Teachers' Guide to
PHYSICS IS FUN
Book Three

BY JIM JARDINE

PHYSICS IS FUN

An introductory secondary school course

Volume One

Volume Two

Volume Three

Volume Four

TEACHERS' GUIDES TO PHYSICS IS FUN

Teachers' Guide to Physics is Fun Books One and Two

Teachers' Guide to Physics is Fun Book Three

Teachers' Guide to Physics is Fun Book Four

Teachers' Guide to

PHYSICS IS FUN

Book Three

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Preface

The general aim of the *Physics is Fun* series of text books is to stimulate and maintain an interest in physics and to develop an understanding of the basic concepts.

Book Three is intended for pupils in the third year of their secondary education and, as such, is an introduction to the more quantitative work of the Ordinary Grade course.

The contents fall into roughly two main parts, mechanics (dynamics) and heat, unified by the underlying theme of 'conservation'.

No two schools can be expected to have identical apparatus and no two teachers have the same idea of what practical work should be performed. For this reason the text book contains more experiments and demonstrations than could be completed in the usual time allocated to physics. In order to help teachers to choose the essentials we have indicated those experiments that we feel are indispensable and we suggest the following rough time table.

Chapters 1 to 5 inclusive should constitute the work of the first term of the third year; Chapters 6, 7 and 8 the second term; and Chapters 9 to 12 complete the year's work.

Book Three contains a large number of stroboscopic photographs. We suggest that one period per term should be spent in demonstrating the technique of taking such photographs and that, other than this, the photographs in the text could be used for home exercises and problems in class.

The chapters in this guide are numbered to correspond to those in the text book. Each contains notes on the experiments/demonstrations (in red print in the text book) and references are given to the Nuffield catalogue of apparatus. Such references are merely the catalogue number—written e.g. (N.21). Each chapter also contains answers to the numbered questions. In many cases the answers are more detailed than one could reasonably expect from a third-year pupil.

The answers to the questions on vectors have all been calculated and so are more accurate than could be obtained from scale drawing. Teachers will have to set their own standards of expected accuracy.

Pupils should not have access to this Guide. To allow them such access would be to defeat one of the main purposes of the course.

References

We have kept references to alternative experiments to a minimum but teachers who wish to try other arrangements will find help in the following books:

Physics for the Inquiring Mind, E. M. Rogers.
How to use Physics for the Inquiring Mind, E. M. Rogers.
Physics Teacher's Guide 4, Nuffield Foundation.
Physics, Physical Science Study Committee, Second Ed. (Heath).
The Science Study Series (Heinemann Educational Books).

Some chapters have sections headed 'Optional Extras'. These are suitable for fifth-year pupils working for the Scottish Higher Grade examinations.

Note on the Organisation of the Guide

Physics is Fun, by Jim Jardine, is a complete course in physics for secondary schools published by Heinemann Educational Books Ltd in four volumes.

The chapter and section numbers in this Guide tally with those in the appropriate Pupils' Book. Each chapter is divided as follows:

(*a*) Introduction.

(*b*) 'Experimental Work', which covers the experiments, demonstrations, and models numbered thus, 11.3, consecutively within chapters and printed in red in the Pupils' Books.

(*c*) 'Answers to Questions', which gives the answers to the questions printed in black italics and numbered thus, (2), consecutively within chapters of the Pupils' Books.

Nuffield Apparatus

The references to Nuffield apparatus given thus, (N.12), refer to the catalogue numbers in the *List of Nuffield Apparatus*.

1 Time (pp. 1–11)

Introduction

This chapter starts with a brief historical survey of the measurement of time and a discussion of the various time-recording devices used through the ages. Much of the work contained in this section could be read and investigated by pupils at home or in science clubs. Experiment 1.5 and Demonstration 1.6 form the core of this section with Experiment 1.8 providing a useful introduction to flash stroboscopes.

The concept of experimental errors (especially those produced via human reaction) is introduced in Experiments 1.9, 1.10, 1.11; and time spent on these experiments is time well spent.

The main part of the chapter is found in Experiments 1.13 and 1.15 and Project 1.14 which demonstrate via experiment the use of stroboscopes and ticker-timers. The pupils should become familiar with the use of these, since they form the basic apparatus for the succeeding chapters.

As a rough guide to time allocation, it would seem practicable to spend at the most three weeks on this chapter, although it would be desirable to complete it inside a fortnight. Suggested methods of grouping experiments to achieve this are given below.

Experimental Work

Experiment **1.1** *and Demonstration* **1.2.** Both of these could easily be done by pupil either at home or in the science club.

Projects **1.3** *and* **1.4** *and Experiment* **1.5.** These three could be attempted simultaneously by a class. Three sets of apparatus for each could be distributed throughout the lab., and pupils could pass from one to another. It would help if pupils had read the relevant *P.I.F.* section beforehand. A double period should suffice.

(See answer to question 6 about counting pendulum swings.)

Demonstration **1.6.** This is difficult to set up—allow time before the lesson starts to try it out.

The two shadows stay in step as the amplitude of the pendulum changes. Pupils should understand from this and from Experiment 1.5, that the period of a pendulum is affected only by length. This point could be emphasised by changing the mass of the bob and the

length of the pendulum. The more able pupil might accept that the motion of a pendulum is plane projection of circular motion. (Turntable (N.154), lamps (N.72 and 73).)

***Demonstration* 1.8.** The motor is running at mains frequency 50 Hz. The neon lamp is also flashing at mains frequency. Each arm of the disc makes $\frac{1}{8}$ revolution per 1/100 second and lamp flashed every 1/100 second. Hence, any one part of the disc appears in the same position on each successive illumination. The disc therefore appears stationary.

Naturally a better effect is achieved in a blacked-out laboratory. (Transformer (N.27), neon lamp (N.66).)

***Experiments* 1.9, 1.10 *and* 1.11.** A double period could be devoted to these experiments although, if time was pressing, a single period would be ample. The experiments in themselves are self-explanatory. Project 1.12 could be done by demonstration and displayed to pupils as they circulate on the other experiments. Instruction for the 'make and break' circuit are given on the reverse of Venner clocks.

***Experiment* 1.13.** (i) This is perhaps the most important single experiment in the chapter. The pupil should be able to find out for himself that it is the *highest* frequency of the strobe which gives a stationary line without double viewing, that is the frequency of the turntable. He should understand why double that frequency gives double viewing and three times it treble viewing, etc. We have found that pupils tend to rotate stroboscopes much too quickly and need a little guidance after some initial attempts.

(ii) From the previous experiment, the pupil should realise that two slits offer two opportunities per revolution to view the blade, and hence reason that the strobe speed multiplied by the number of slits equals the frequency of the blade.

Start with a lump of plasticine about 250 g. A marked increase in frequency is obtained when half of the plasticine is removed.

A useful additional experiment can be done using a tuning fork and plasticine when a decrease in pitch (i.e. frequency) is heard when the plasticine is stuck on one prong of the fork.

(iii) This demonstrates further the use of an increased number of slits to increase the 'viewing' frequency and is a useful introduction to the use of ticker-timers.

If time is pressing, (i) and (iii) should be attempted with (ii) being omitted.

(Hand strobes (N. 105/1), hack-saw blades (N.120).)

***Project* 1.14.** Clamp the timer to the bench so that the tape falls

vertically through the slits, thus reducing friction. A 0·5 kg mass gives a satisfactory result. (See Fig. 73 in the pupils' book.)
(Transformer (N.27), timers (N.108/1).)

We would recommend this to be done by demonstration during the same lesson as, or immediately after, Experiment 1.13 for the sake of continuity.
(Flash strobe (N.134/2).)

We suggest that stroboscope photography should be introduced now. A suitable experiment photographs a golf-ball falling about 1 metre. The best results are obtained if the strobe lamp is held above the ball, rather than to the side or in front. Use 1,500 flashes/minute on the lowest scale with a matt blackboard as background.

Alternatively, illuminate the ball from above with a steady beam from a projector, and fix a motor-driven strobe-disc in front of the camera, set at 5 rev/s, with 6 slits.
(Camera (N.133), xenon flasher (N.134/2), motor strobe (N.134/1).)

ANSWERS TO QUESTIONS

1. Independent of user.
Independent of when used.
Independent of where used.
Easily reproduced.

2. Pulse rate or heart beat.

3. Varies from individual to individual.
Varies for any individual according to his physical condition at the time of measurement.
Cannot be incorporated in a mechanical timing device.

4. Uncertain presence of sun during daytime.
No sun at night.

5. The period is isochronous, i.e. the period of swing is the same even if the amplitude of swing changes a little.

6. Time the period of a simple pendulum over a large number of swings for a variation in amplitude. As long as the amplitude is small ($\theta = \sin\theta$) the period is the same. In counting swings, count 3, 2, 1, 0, 1, 2, 3 and start the watch at 0. Often an error arises by counting 1 on the first passage of the pendulum past the zero position (see Experiment 1.5).

7. 0·00008% or 8×10^{-5}%.

8. 50 Hz.

9. No. The operator's reaction time would introduce an error of at least 0·2 seconds (i.e. two hundred thousandths of a second) which make a reading, taken to one thousandth of a second, ridiculous.

10. $2\frac{1}{2}$ s.

11. 36 Hz.

12. If the lathe is rotating at the same frequency as that of the strobe lamp, then the lathe appears stationary because each part of the lathe appears in the same position on each successive illumination. When the lamp frequency is now increased, any point on the lathe will not have made a complete revolution between two flashes of the lamp. With each successive flash, each point on the lathe will appear to have rotated slightly backwards. Hence the effect of the lathe rotating in the opposite direction is obtained.

13. The speed of revolution, i.e. the frequency of rotation of the car wheels, is less than the frame speed of the film, i.e. the number of pictures shown per second. The same effect as in the previous example is observed. Since there are spokes on the wheel the situation is slightly more complex. The spokes can move in the time between flashes to the position of the next, or the second or the third spoke, etc. So there will be many positions of apparent rest and of forward or backwards movement as the wheel speeds up.

14. These discs have marked on their surface three concentric rings of radial lines; each set may be of a different colour. The number of lines on each disc is chosen so that, when the disc is illuminated by a mains-operated lamp (50 Hz), by adjusting the variable speed control the ring corresponding to a required disc speed (say 45 rev/min) appears stationary—at least the lines on that ring appear stationary while the other two are simply blurs of colour. Remember that in a mains lamp the amplitude varies 100 times per second. This is merely a further application of the 'stroboscope' effect discussed in previous questions.

15. No. The discs must be illuminated by a mains-operated (50 Hz) lamp. In daylight they would show all the lines blurred.

16. Reduces.

17. Lowered in pitch.

18. 24 Hz.

72 dots.

Tape is pulled through timer and the number of dots marked during the period noted. The number of dots divided by the timer frequency—in this case 24 dots/second—gives the time in seconds.

Two people are needed—one to pull tape, the other to operate timer.

The tape should be moving before the timer is started. Pulling the tape from rest produces a mass of dots at the starting point.

There is an error even if the tape is moving, for the beginning of the 3-second interval might not coincide with the making of a dot on the tape. Errors due to human reaction time arise.

2 Distance and Displacement (pp. 12–17)

Introduction

The principal function of the work of this chapter is to introduce to the pupil the meaning of the terms vector and scalar. This is done by discussing the difference between distance and displacement. A useful start can be made by quoting the example of a motor cyclist who breaks down on a bleak moor. He telephones home to say that he has travelled a distance of 4 miles but his searchers would have less bother if he had given his displacement, say 4 miles due East.

It is common for pupils to become bored at this stage if too much time is spent on this subject, so that this section should be completed without delay (perhaps within a week) but not at the expense of insufficient understanding.

Pupils should be encouraged to draw rough space diagrams followed by accurately and neatly drawn vector diagrams accompanied by the chosen scale.

It is all too easy to dwell on the 'chalk and talk' aspect of work here—three periods are sufficient.

Experimental Work

Demonstration **2.1.** The apparatus for this is simply constructed and can easily be made in school. More elaborate apparatus may be necessary later in the course, when accelerated motion is considered.

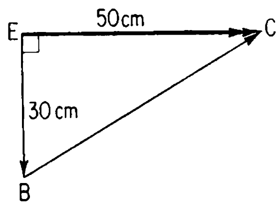
Demonstration **2.2.** Any of the model cars used in the first year are suitable. This demonstration is not too easy! The analogy of a dwarf on a board is good and should be used, or a similar one adopted. Woolworths sell a walking robot which, in addition to providing an entertaining diversion, can be used to illustrate displacement and frames of reference very clearly.

In a *P.S.S.C.* film (see Chapter 3) elastic bands with arrows fitted to them are used effectively to represent vectors. Although the film treats the subject in greater depth than is needed here, the earlier parts of it are of value.

We have found that pupils often finish this chapter with the idea that vectors apply only to one plane. The same difficulty arises with forces, if over-emphasis is placed on the parallelogram theorem. Examples of three-dimensional forces are easily set up. An extension to three-dimensional vectors is then easy.

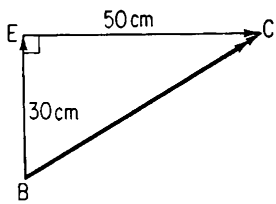
ANSWERS TO QUESTIONS

1. (*a*) 284 miles.
(*b*) 42 miles West.
2. 42 miles.
3. Motion in a straight line (rectilinear) in the same direction.
4. (*a*) 40 miles.
(*b*) 0.
5. 2 yards towards B.
6. *Vector*—Force, weight.
Scalar—Mass, length, temperature, volume, density.
7. 4·64 mi. 27° 14′ E. of N.
8. 9·84 mi. 10° E. of S.
9. 125 m. 36° 52′ S. of E. (if man crossing W. to E.).
36° 52′ S. of W. (if man crossing E. to W.).
10. 0·8 m. 57·5 W. of S.
11. 13 mi. 16° N. of W.
12. If the board's motion relative to the table occurs simultaneously with that of the car relative to the board and if the motion in each case is of uniform velocity. (Later we will discuss accelerated motion.)
13. (*a*)



Resultant displacement of chalk (relative to Earth) $= \overrightarrow{EC}$
$= 50$ cm
(horizontally to right).

(*b*)



Resultant displacement of chalk (relative to board) $= \overrightarrow{BC}$
$= 58{\cdot}3$ cm
(59° 1′ to right of vertical).

3 Speed and Velocity (pp. 18–28)

Introduction

In this section vectors are again encountered, this time to distinguish between speed and velocity.

The pupils are introduced to the construction of tape-charts and speed/time graphs. Gummed tape is useful. The meaning of area under a curve, particularly speed/time curves, is explained.

There are only two experiments mentioned in the text and both of them ought to be attempted. A time limit of two weeks (or four periods) should be sufficient.

Experimental Work

Experiment **3.1.** It is important that pupils realise they are measuring *average* speed over the whole 30 metres although the partner can be travelling at various values of instantaneous speed at different points along the corridor.

Experiment **3.2.** Half the class could be engaged on this while the remainder are in the corridor doing Experiment 3.1.

(*a*) Pupils have already used timers in Chapter 1 so that no difficulty should be encountered here.

(*b*) The idea of a length of tape representing average speed is a difficult one for pupils to grasp. Time must be spent explaining that each length of tape (consisting of say 10 ticksworth) is the distance travelled in $10 \times 1/50$ second, i.e. the number of cm travelled per $\frac{1}{5}$ second, which is a measure of speed.

Some pupils find difficulty in converting cm/$\frac{1}{5}$s to cm/s and a simple treatment such as 10 cm in one-fifth of a second equals 50 cm in one second, i.e. 50 cm/s, will help.

Pupils will readily see that if the second of two consecutive tapes is longer than the first, then the distance gone in the same interval of time has increased and hence the average speed has increased.

If the outline of the tape-chart is marked in heavy ink (a felt pen is suitable), the shape of the graph is seen more clearly, and a useful introduction is given to drawing the graph without sticking the lengths of tape on to paper.

At this stage, every pupil should produce his own tape-chart. Groups of four pupils can work quite easily with the same timers.

***Project* 3.3.** Quite definitely a project and should be treated as such—left to home or science club.

***Project* 3.4.** A discussion of this would be sufficient, since photographs of the motion are provided in the text book.

Although no experiments are included on the work in relative velocity, we have found that 'chalk and talk' can be augmented to give better understanding and interest by the use of walking robot (Chapter 2) or toy car moving on a moving drawing board. More elaborate apparatus may have to be devised for those pupils who are unable to visualise these situations.

ANSWERS TO QUESTIONS

1. (*a*) Constant speed.
(*b*) Constant speed.
(*c*) Uniformly increasing speed starting from rest.
(*d*) Uniformly increasing speed starting from a particular initial speed.
(*e*) Uniformly decreasing speed starting from a particular speed and finishing at rest.
(*f*) From rest, gains speed, moves at steady speed, slows up very rapidly and comes to rest.

Yes. (*a*) and (*b*) could represent the same motion provided the scales on the speed axis were adjusted.

2. No. The time between two successive dots is 1/50 second, and therefore the time between the first and tenth dots is 9/50 second.

Hence, the speed is $\frac{1000}{9}$ cm/s not 1 m/s. This is a mistake similar to the one mentioned in Chapter 1, question 6, about the pendulum swings.

3. 40 mi/h E; -40 mi/h W; zero N; zero S.

4. Uniform velocity.

5. At the top where successive positions are farthest apart.

6. At the bottom where successive positions are closest together.

7. Constant.

8. Pull the tape through the timer for a certain measured time and divide the number of dots produced by the number of seconds. An alternative method would be to find the highest stroboscope frequency at which the timer appears stationary without double viewing. It is best to start with the strobe flashing very fast and to reduce the frequency until multiple viewing ceases and a single position of the vibrator is seen.

9. No.

10. 50 cm/s; 0·5 m/s.

11. Between B and C; 67·5 cm/s; 0·675 m/s (greatest).
Around D; 22·5 cm/s; 0·225 m/s (least).

12. Average speed over 1/50 second.

13. Increasing uniformly, as the distance between the dots increases regularly.

14. It doesn't. It remains constant.

15. A boy walking.

16. 3 m, 4 m, 2 m, 1 m, 10 m.

17. 2·5 m/s.

18. 6 m.

19. 22 m.

20. 2·75 m/s.

21. When the passenger is walking towards the rear of train.

22. The speed of the aircraft relative to the air.

23. The air itself may have a speed relative to the Earth, e.g. in high wind conditions.

24. The air.

25. The board, or the Earth.

26. It is not constant.

27. No.

28. The small white dot at the centre.

29. Successive positions of the small dot are spaced equally.

30. The bicycle (or the can).

31. No. Its speed is constant but its direction is always changing.

32. Velocity of dog relative to river $=3{\cdot}6$ m/s 56° 19′ N. of E.
Velocity of dog relative to Earth $=3{\cdot}16$ m/s 71° 34′ N. of E.
Magnitudes found by Pythagoras or by scale drawing.

33. The man is taking the pier as his frame of reference and, since his velocity relative to the ship and the velocity of the ship relative to the pier give him a zero resultant velocity relative to the pier, he can regard himself as at rest with respect to pier. The lady, although at rest relative to the ship, has, due to velocity of ship relative to pier, a resultant velocity relative to the pier. The young man's assertion is therefore academically sound although perhaps not the normal way of looking at the situation.

34. 608 mi/h at 80° 30′ S. of W.

35. (*a*) Distance—scalar.
(*b*) Displacement—vector.
(*c*) Velocity—vector.
(*d*) Speed—scalar.
(*e*) Force—vector.
(*f*) Mass—scalar.

36. Looking at clock face:
(i) 14·14 cm 45° to right of downwards vertical.
0·0157 cm/s 45° to right of downwards vertical.

(ii) Zero.
Zero.
(iii) 14·14 cm 45° to right of upward vertical.
0·0052 cm/s to right of upward vertical.

37. 35 mi.
25 mi. 36° 52′ S. of W.
35 mi/h.
25 mi/h 36° 52′ S. of W.

Average speed is a useful idea, but average velocity has little meaning here.

38. 17·14 mi/h.
12·12 mi/h 45° E. of N.

39. (i) 300 m.
(ii) 100 m S.
(iii) 0·83 m/s S.
(iv) 2·5 m/s.

40. 15·03 m/s 86° 10′ N. of W.

41. 342·9 mi/h.
Zero.

42. 100 minutes.

4 Acceleration

Introduction

This chapter is devoted entirely to the accelerated motion of bodies, mainly acceleration from rest. Several experiments are included in the text book and it is a matter of personal choice and time available which decide which ones should be done.

We recommend that pupils should attempt Experiments 4.1, 4.4, 4.8(*b*) as the basis of the work. Experiments 4.2, 4.6, 4.7 could best be done as demonstrations with the help of the pupils.

The equations of motion are introduced, derived and formally stated. It is all too easy for the emphasis to slip towards the mechanical learning and regurgitation of these equations. They are derived mainly via experimentation, and it is hoped that this will lead to better understanding.

Mere recall of the equations is neither sufficient nor desired—it is better that a pupil understands that final velocity equals initial velocity plus change in velocity than that he can write down from memory $v = u + at$, or that distance gone is proportional to the square of time rather than writing automatically (?) $d = \frac{1}{2}at^2$.

Experimental Work

Experiment **4.1.** All pupils must do this. They can work in groups of anything up to four pupils quite comfortably but each pupil must produce his own tape-chart. Again we recommend the drawing of outlines in heavy ink and marking the centre of the top of each tape quite distinctly.

It should be pointed out that the choice of the number of tickesworth depends on the size of the page of the pupils' books and also on the ease of calculation, e.g. 10 tickesworth = 1/5 s but 7 tickesworth = 7/50 s.

Again the manipulation of numbers is encountered, e.g. 10 cm/$\frac{1}{5}$s/$\frac{1}{5}$s and individual needs and difficulties of pupils must be dealt with one at a time.

The lesson could conclude with the comparison of results from pupils using the same slope and those using different slopes.

Experiment **4.2.** This is more difficult than first appearances suggest. If one pupil is delegated to mark the position at each second and several practice runs are used, favourable results can be obtained.

From these results, pupils should see that the extra distance gone each second is the same, and that the total distance gone is proportional to the square of the time.

Many pupils find the deduction of uniformly accelerated motion from these results too difficult for them. They often derive much help if question 14 is treated in the same way. The information given in question 14 can be used to build up a similar table of results.

***Demonstration* 4.3.** It is a bit of a luxury to spend time doing this experiment when a photograph is provided. A discussion of the photograph and the questions should suffice. It ought to be immediately obvious that the two spheres stay in step, i.e. they are accelerated at the same constant rate.

***Experiment* 4.4.** This is again a 'must'. Little need be said about this experiment except that a mass of 0·5 kg to 1 kg gives optimum results (depending on the strength of paper used). We have found that two ticksworth are suitable time intervals. A value in the range 8·5–10·5 m/s^2 should be obtained.

***Experiment* 4.5.** This experiment could safely be omitted in the interest of saving time with no loss of learning on behalf of the pupils.

***Experiment* 4.6.** We have found that many teachers hope to improve on the pupil value of g from Experiment 4.4. For this purpose, the apparatus described in the text book is admirable. An answer of about 9·5 m/s^2 can be obtained without much difficulty. Instructions are given on the clock for the 'stop-start' circuit.

***Project* 4.7.** This can be done in science club at or home. We have found that the pieces of metal hit the ground at regular intervals provided the bottom piece is touching the ground before the string is released.

***Project* 4.8.** Sufficient instructions are given in the text book for this, if it is to be treated as a project.

Part (*b*) forms a useful extra experiment should time permit.

ANSWERS TO QUESTIONS

1. A film of the speedometer if taken by the cine camera, i.e. one picture taken every 1/18 second. If the film is then projected at a slower speed ('slow-motion') or observed in a film editor, the readings can be noted.

2. A straight-line graph through the origin.

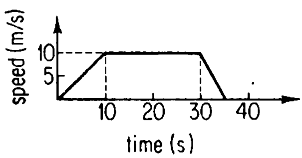
3. 20 mi/h to 40 mi/h (although 10 mi/h to 50 mi/h might be acceptable).
4. The speed remains constant.
5. (*a*) 1 m, 4 m, 9 m, 16 m.
   (*b*) 1 m, 3 m, 5 m, 7 m.

The distance covered each second is 2 m further than the distance covered in the one before.

6. $v=u+at$
   $v=at$
7. 2 m/s^2; 26 m/s.
8. 6 m/s; -4 m/s^2.
9. 10 m/s, zero, -10 m/s.
10. 80 m/s^2.
11. After 5 seconds, i.e. at half the total time of motion.
12. 20 m/s, 2 s, 4 s, 45 m.
13. From equation (3) $d=\frac{1}{2}vt$, i.e. d is proportional to v multiplied by t; but v itself is proportional to $t(v=at)$.
d is proportional to $t^2(d=\frac{1}{2}at^2)$.
14.

d	$\bar{v}=\dfrac{\Delta d}{\Delta t}$	$a=\dfrac{\Delta v}{\Delta t}$
0 cm	–	–
3	3	–
8	5	2
15	7	2
24	9	2

15. 30 m; 1·25 m/s^2.
16. 2·5 cm/s.
17. 540 m/s; 48,600 m; 270 m/s.
    At $t=90$ s; 60 m/s; 20 s.
18.



275 m, 5 m/s, 5 m/s, 10 m/s.

19. 240 m/s^2.
20. 0·25 m/s^2.
21. Taking $d=50$ cm, $t=8/25$ s, $g=9{\cdot}76$ m/s^2.
22. 460·8 m; 96 m/s (taking $g=10$ m/s^2).

23. 25 m; 1 s; 1 s.

24. v = final velocity m/s
u = initial velocity m/s
a = acceleration m/s^2
t = time s
v = average velocity m/s
d = displacement m

25. Change in velocity.

26. This equation is only true when $u=0$.

Then $v/2$ = average velocity and $\frac{v}{a}$ = time.

27. Again $u=0$. $\frac{at}{2}$ is the average velocity, the velocity gained in half the total time.

5 Newton I   Definition of a Force
(pp. 29–43)

Introduction

Mass, Measurement and Motion. Resistance to acceleration is the experimental manifestation of mass. Experiments 5.1 and at least one of 5.2, 5.3, 5.4 should be done after revising the demonstrations in Book One. Mass may then be defined. (2–3 periods)

Aristotle and Common Sense. The discussion here leads the class towards the idea of friction as the agency responsible for the retardation of 'freely' moving bodies. ($\frac{1}{2}$ period)

Galileo and Gravity. The effect of friction on freely falling bodies led Galileo towards experiments in which he tried to approach frictionless motion. Experiments 5.5 and 5.6 should be followed by a discussion of Galileo's thought experiments. Modern equipment is used in 5.7 and/or 5.8 to show how we can now watch a body moving almost without friction. Newton's first law follows naturally provided that the above discussion is not rushed. ($1\frac{1}{2}$–2 periods)

Projectiles. Experiment 5.9 and one of 5.12 and 5.13 should suffice to demonstrate the independence of horizontal and vertical motions of a projectile. (3–4 periods)

Let Newton be. Newton's first law crystallised and optional problems on projectiles. (2 periods)

Experimental Work

***Experiment* 5.1.** It doesn't hurt because the force exerted by the hammer hardly moves the great mass of the books, though it forces the tack in. Other experiments to illustrate inertia include the tumbler, card and penny, snatching a book from the middle of a pile, pulling a sheet of paper from under a beaker of water.

***Experiment* 5.2.** It is important that pupils handle this apparatus themselves to give them the feel for inertia.

***Experiment* 5.4.** This apparatus is available from the usual suppliers but, if it is home-made, it is essential to minimise slackness at the ends

of the hacksaw blades. Otherwise the oscillations will die away quickly.

***Experiment* 5.5.** Plastic curtain rail is convenient and it should be firmly clamped at several points.

***Experiment* 5.6.** As in Experiment 5.4 it is essential that the pendulum support and the clamp should be rigid to minimise energy losses.

***Demonstration* 5.7.** Linear air tracks are available commercially. Before purchasing it would be wise to make sure that the accessories available are sufficient to cover this demonstration, 7.4 and 7.5. For good results careful levelling is necessary. Illumination of the indicator on the Perspex vehicle is probably best done by placing lights to shine along the line of the track from each end. This gives sharper images on the photographs than full-face illumination. When using a Xenon flasher (Dawes Instruments, Griffin and George, W. B. Nicolson, Philip Harris), which has a narrow beam, careful alignment of the beam and the track are necessary. Further useful information on the techniques of strobe photography can be found in the *Scottish Education Department Science Newsletters*, No. 1, page 11; No. 2, pages 14, 16–19. No. 3, page 31, gives details of construction of a linear air track.

***Demonstration* 5.8.** It would be wise to practise the use of this apparatus before performing in front of a class. Level the glass carefully before attempting any photographs. Illumination by means of a photoflood or xenon lamp should be oblique to avoid reflection off the glass. The plate should be cleaned carefully with a rag moistened with alcohol. A long cable release for the camera is essential to avoid vibration when operating the shutter.

To take a photograph, turn on the strobe lamp, set the camera for brief time exposure (use a wide aperture for a first try), open the shutter and give the puck a gentle push. When the puck has travelled the required distance, close the shutter. Strobe flash rate should be about 5 per second.

***Project* 5.10.** This interests a class because it is the first time they have analysed a graph that has drawn itself.

***Project* 5.11** is Experiment 5.9 done again.

***Demonstration* 5.12.** This is well worth showing. If the stroboscopic lamp is driven at the same frequency as the vibrator, say 50 Hz from a mains transformer, the drops can then be 'stopped'. A piece of paper on a vertical drawing board, placed close behind the drops,

can then be used to mark their positions. The motion may then be analysed.

Demonstration **5.13.** Almost any cork-firing pop gun may be used. Practise firing at a stationary target at fairly close range to make sure that the cork can be projected in the direction in which the gun is aimed. Clamp the gun to reduce human error in firing it.

ANSWERS TO QUESTIONS

1. If the body is hung on a spring, the latter does not stretch. The beam balance also depends on the force of gravity, so it is no use.

Pull the body using the spring balance. The resultant motion will give an indication of the mass. The expected answer is 'neither'.

2. Not necessarily.

3. It is not easily moved.

4. Empty can.

5. Neither. It is due to difference in mass.

6. The lorry.

7. It is more difficult to stop the greater mass.

8. A football. (This answer will have little to do with physics!)

9. A smaller force will get it moving.

10. Kilogramme.

11. Platinum.

12. International Bureau of Standards at Sèvres in France, near Paris.

13. It is easier to push when the friction is reduced by polishing or by the block rolling on polystyrene beads.

14. By ball or roller bearings and by lubrication.

15. By streamlining and polishing the surface.

16. The weight of string on the right-hand side is greater.

17. No.

18. (*a*) Molecules in Brownian motion, (*b*) planets and satellites.

19. No.

20. No.

21. 24 ft/s^2.

22. 32 ft/s^2.

23. The air resistance to the motion of the lead is a smaller fraction of its weight than is the case with the paper.

24. In a vacuum.

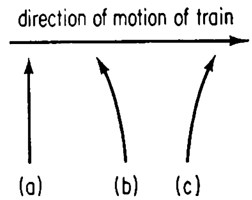
25. No. The length.

26. Once started it kept moving almost at a steady speed in a straight line.

27. As question 26.

28. No.

29. Yes.
30. Yes, by upward pressure of the trapped carbon dioxide.
31. No.
32. Two.
33. Yes.
34. Yes.
35. It accelerates (uniformly).
36. No.
37. No.
38. Forwards. The drag of the ground decelerates your feet. Your body carries on moving forward.
39.



(*a*) The ball and carriage have the same forward velocity. Therefore the relative motion of the ball to the carriage is at right angles to the carriage.
(*b*) The ball has a steady velocity forward while the carriage accelerates. The ball has an increasing backward velocity relative to the carriage.
(*c*) The ball has an increasing forward velocity relative to the carriage, which is decelerating.

40. (*a*) 100 m/s, (*b*) 200 m/s, (*c*) 2,000 m, (*d*) 2,000 m, (*e*) 100 m/s, (*f*) 100 m/s, (*g*) 2,830 m at 45° below the line of flight, (*h*) 141 m/s at 45° below the line of flight. 'Average velocity' must be regarded with some mistrust.
41. Carbon dioxide puck, linear air track rider, space ship, stone on ice (nearly), trolley on compensated slope.
42. Unbalanced forces change velocity.
43. Yes—it slows down moving bodies.
44. To stop the motorist quickly needs a large backward force. This is better provided by a safety harness than by the windscreen.
45. To go round a corner the bus must have (the direction of) its velocity changed. This requires an external force on the tyres at right angles to its motion. The centre of gravity of the bus tends to carry on in a straight line and to tip the bus over.
46. The centre of gravity is kept low so that the sideways force on the tyres has a small moment about the centre of gravity. The width of the bus is made as large as is practical so that its weight has a large moment about the outer wheels.
47. (*e*) is correct. All forces are balanced.

48. Yes, its weight.

49. Yes.

50. Newton I predicts straight-line motion in the absence of gravity. Its weight changes its velocity (in direction only) so that it continually falls towards the Earth but never reaches it.

51. Air friction, when combined with the weight of the bullet, gives a resultant directed backwards from the vertical. The bullet slows down and spirals towards the Earth's centre. Later, when elliptical orbits are being done, it becomes obvious that the whole ellipse must be outside the Earth, so a bullet cannot be fired directly into orbit.

52. You would apparently 'float' in the satellite.

53. You would still be pulled by gravity.

54. You would have the same orbital velocity and the same vertical acceleration as the satellite. You would therefore have no motion relative to the satellite.

55. There is a misprint in the 1966 edition of D for E.

The bullet would describe an ellipse, the Earth being at one focus of the ellipse, or it might 'escape' from the Earth's gravitational field and move into 'space' under the influence of other fields, e.g. the Sun's or the Moon's.

56. The trolley's motion is evident from the successive images of its wheel, visible at the bottom of the photograph. (It is also possible that the camera moved from right to left while the trolley was stationary.)

The horizontal displacement of the ball indicates that the camera was fixed to the bench.

The time taken is eight flash intervals = 0·32 s.

The vertical distance = 0·512 m.

By measurement we can find the distance the trolley moves forward. In this case it is the same as the distance the ball falls, 0·512 m. The time is 0·32 s. Therefore the trolley's speed, obviously constant from the photograph, is 1·6 m/s.

57. Fig. 98(*a*) shows a vertical, uniform acceleration. Fig. 98(*b*) shows motion with constant velocity. Fig. 98(*c*) shows a combination of these two which could be produced by projecting the ball horizontally in a vertical gravitational field.

The camera would be placed horizontally in line with the initial motion in (*a*), above or below the ball's path in (*b*), and horizontally to the side of the plane of the ball's path in (*c*).

6 Newton 2 How to Measure Force
(pp. 44–57)

Introduction

Force. This section establishes the relationship between force, mass and acceleration embodied in Newton's second law. Experiments 6.2, 6.3 and 6.4 are important. Again the approach should not be hurried, and we can get useful guidance from the Nuffield *Physics Teachers' Guide* 3 (pp. 247–75) and *Guide* 4 (pp. 29–130).[1] (5 periods)

Gravity. The concept of a gravitational field is introduced using the Earth's field as an example. (1–2 periods)

Vectors. The parallelogram and triangle laws are treated lightly, no attempt being made at formal statement of the general conditions for equilibrium. Experiments 6.5 and 6.6 are important. (3 periods)

Optional Extras. A sophisticated look at Newton's second law. (2 periods)

Experimental Work

***Experiment* 6.1.** The plane should be smooth for regular motion. Don't expect to get too high a standard of uniformity in the spacing of the dots. Pupils need plenty of practice runs.

***Experiments* 6.2 *and* 6.3.** Use elastics which have not been over-stretched. Renew them after using them with two or three classes. Make pupils practise keeping the elastics horizontal and stretched the same amount during all the runs. They should stand opposite the centre of the track, and not move their feet. Teachers will find it very helpful to have done this themselves before attempting it with a class. F/a should be constant.

***Experiment* 6.4.** Friction compensation must be rechecked each time a trolley is added. $m \times a$ should be constant.

***Experiment* 6.5.** This method of establishing vector laws is worth trying even though the traditional boards and pulleys are available.

[1] Nuffield Foundation, 1966. *Physics Teachers' Guides* (London: Longmans Green and Co Ltd, and Penguin Books Ltd, 1966).

The directness of the method used to apply the forces and measure them may well help slower pupils to grasp the principle. Use good-quality elastic.

Try also three spring balances attached to a ring. Hold them in a straight line, two on one side, one on the other. Watch the changing readings as the two are pulled apart to nearly 90°.

***Experiment* 6.6.** Remarks about Experiment 6.5 apply here also.

ANSWERS TO QUESTIONS

1. Falling bodies have constant acceleration. Therefore the weight is constant near the Earth's surface.

2. There should be agreement within 5%.

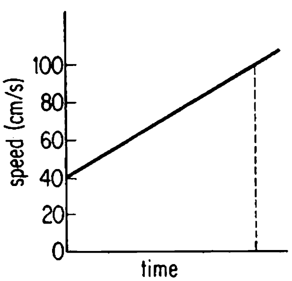
3. a is proportional to F.

4. a is proportional to $\frac{1}{m}$, or $m \times a$ is constant.

5. Acceleration $= 4$ cm/s², for the force is only $\frac{1}{3}$ of what it was. (Hang three spring balances end to end with a weight on the end. What does each read?)

6. The speeds are 40 cm/s, and 100 cm/s.

The graph is roughly thus:



The area represents the distance gone, i.e. 1 m. The average speed is 70 cm/s. Therefore the time is 1·43 s, and acceleration $= 42$ cm/s².

Use a spring balance to find the force that is just holding the body at rest on the plane.

7. Acceleration $= 0{\cdot}125$ m/s²; force $= 0{\cdot}1$ N; the same; the same.

8. 0·16 N.

9. In opposition to the motion, 24 N.

10. (*a*) Its average velocity ($= \frac{\text{displacement}}{\text{time}}$) is constant. Therefore its velocity is constant.

(*b*) Newton's first law implies that *no* unbalanced force acts on it.

11. The pistons in a reciprocating engine reverse their direction of motion frequently. Hence their velocity must change rapidly. Hence there is a large acceleration. An unbalanced force is needed (to produce this acceleration) which is proportional to the mass. The mass is kept as low as is possible to reduce this force, which must be applied to the piston by the connecting rod acting through its bearing in the piston.

12. The acceleration of the car is produced by the excess of the pull of the engine over frictional drag. The pull of the engine is limited but the drag increases with speed. A speed is then reached at which the engine's pull equals the drag. There is then no further acceleration and the speed remains constant.

13. Distances gone in successive $\frac{1}{10}$ second are 6·5, 8·0, 9·0, 10·5, 12·0 cm.

Velocities in successive intervals are 65, 80, 90, 105, 120 cm/s.
Increments of velocity are 15, 10, 15, 15 cm/s in each $\frac{1}{10}$ s.
Average acceleration = 13·75 cm/s per $\frac{1}{10}$ s
= 137·5 cm/s^2 = 1·375 m/s^2.

$$\text{Mass} = \frac{\text{force}}{\text{acceleration}} = \frac{0{\cdot}5\ (\text{N})}{1{\cdot}375\ (\text{m/s}^2)} = 0{\cdot}36 \text{ kg (approx.)}$$

14. (*a*) $\text{Mass} = \dfrac{10^{-20}}{10^{10}} = 10^{-30}$ kg.

(*b*) $\text{Vertical acceleration} = \dfrac{\text{force}}{\text{mass}} = \dfrac{3 \times 10^{-15}}{1{\cdot}66 \times 10^{-27}} = 1{\cdot}8 \times 10^{12}\ \text{m/s}^2.$

Since there is no horizontal force, its horizontal velocity would remain constant. (Newton I)

15. Force on 2 kg mass = $2 \times 9{\cdot}8 = 19{\cdot}6$ N or 2 kgf.
Force on 5 kg mass = $5 \times 9{\cdot}8 = 49{\cdot}0$ N or 5 kgf.
Force on m kg mass = m × 9·8 N
= m kgf.

16. Yes.

17. The Earth is flattened at the poles and hence the falling body is nearer the Earth's centre at the poles and its weight is greater.

The Earth spins. Therefore a body at the Equator is describing a circle equal to the Earth's radius. Hence some of its weight is used to keep it moving in this circle.

These two reasons are inter-related for it is the Earth's spin that produces the flattening at the poles.

18. Since the downward acceleration at the poles is greater, the pendulum would fall faster and its period would be shorter.

19. The error is approximately $\dfrac{10-9{\cdot}8}{10} \times 100 = 2\%$.

20. Since $\dfrac{F}{m} = a$ when F is in newtons, m in kg, and a in m/s^2, then N/kg = m/s^2.

21. The weight of the 18 kg box = 180 N.
The unbalanced force on the box = 198 − 180 = 18 N upwards.

$\therefore$ The acceleration $= \dfrac{18\text{ (N)}}{18\text{ (kg)}} = 1\text{ m/s}^2$ upwards.

Work done by the man = 198 × 5 = 990 newton metres = 990 J.
He has given the box gravitational potential energy and kinetic energy.

(180 × 5 joules) + (18 × 5 joules)

22. (*a*) It burns fuel and its mass decreases. This increases its acceleration.

Its weight decreases as it leaves the Earth. This increases its acceleration, which is produced by the excess of thrust over weight + friction.

The atmosphere thins. Therefore the frictional drag decreases. Hence the acceleration increases.

(*b*) Assuming the tension in the spring is proportional to its extension, the spring exerts an additional force = 3 times its weight. Its weight produces an acceleration of $g = 10\text{ m/s}^2$. Therefore, by Newton II, its acceleration is $3\,g = 30\text{ m/s}^2$.

$$\begin{aligned}\text{Thrust} &= \text{weight} + \text{unbalanced force}\\ &= 10^4\text{ kgf} + 3 \times 10^4\text{ kgf}\\ &= 4 \times 10^4\text{ kgf} = 4 \times 10^5\text{ N.}\end{aligned}$$

23. The block moves faster at C.
At B it accelerates. The force on the back is greater than the force on the front.
Pressure at A is greater than that at C.
An unbalanced force acts where it is accelerating, near B.

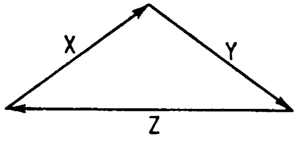
24. $0{\cdot}3\text{ m/s}^2$; 0·6 m.

25. Three forces act on the ring.

26. Yes.

27. *E* is equal in size but opposite in direction to *R*.

28.



The arrows follow each other round the trinagle.

29. Yes.

30. No. *E* is not opposite to *R* (the resultant of *X* and *Y*).

31. It would turn under the couple exerted by *R* and *E′*.

32. The forces must be concurrent.

33. Their vectors form a closed triangle and they must be concurrent. (Parallel forces meet at infinity.)

34. (*a*) $F=0{\cdot}2$ N, $0{\cdot}4$ m/s^2
(*b*) $F=0{\cdot}193$ N, $0{\cdot}39$ m/s^2
(*c*) $F=0{\cdot}173$ N, $0{\cdot}35$ m/s^2
(*d*) $F=0{\cdot}142$ N, $0{\cdot}28$ m/s^2
(*e*) $F=0{\cdot}1$ N, $0{\cdot}2$ m/s^2

35. 1500 N.

36. 20 kg.

m accelerates downward and the 10 kg mass upward. Because the tension in the rope will have to be bigger than 10 kg to support the 20 kg of *m* and the pulley. The rope no longer pulls vertically upward and only its vertical component lifts *m* and the pulley.

37. No horizontal force acts (air friction negligible). Therefore there is no horizontal acceleration. Hence the ball travels equal distances in equal times. Gravity acts vertically. This is unbalanced so that the ball has the acceleration due to gravity.

38. 59·1 N, 1,180 m/s^2, constant horizontal velocity, constant vertical acceleration. Sketch as Fig. 119 in text.

39. 22·5 N.

40. Sand.

41. Bend at the knees.

42. $1{\cdot}5 \times 10^6$ N downwards.

43. $2{\cdot}67 \times 10^{-3}$ s.

44. 0·2 s.

45. 4 m/s^2, giving a force of 200 N; 40 m/s^2, giving a force of 2,000 N; 400 m/s^2, giving a force of 20,000 N.

Table gives $F \times \Delta t$ constant.

46. The collision process takes time to complete. The fly, in a slow-motion film of the impact, would squash slowly and the window of the train would give slightly. Therefore at no instant would the *whole* of the fly be stationary nor the whole of the train. The point on the train at which the fly struck would, during the collision, give so as to move backwards, stop, and then spring forward again.

47. Force = 375 N, impulse = 7·5 N s or 7·5 kg m/s.

48. Time = 5 s.

49. Force = 2,000 N.
Force on wall = 40,000 N.
Impulse = 20,000 kg m/s.

50. Mass = 6·12 kg. [Taking $g = 10$ N/kg, mass = 6 kg.]

Gravity acts downward and the spring balance pulls upwards. These forces are equal, therefore there is no unbalanced force.

The reading increases.

The salmon and balance are dropping with a downward acceleration of 4·9 m/s^2 (or 5 m/s^2).

Yes. Its weight.

It would read nothing while he was falling freely.

(*a*) It would read 60 N.
(*b*) It would read 60 N.
(*c*) Less than 60 N. Zero, if gravity provides all the retardation.

(*d*) More than 60 N.
(*e*) More than 60 N.
(*f*) Less than 60 N. Zero, if falling freely under gravity.

It would always balance on a beam balance or Butchart balance whatever the gravitational field.

Each of these machines depends on balanced moments.

51. Acceleration $= -4$ m/s^2.
Force $= 8$ N, due to friction between block and plane.

52. During quick acceleration the limiting frictional force is not enough to give the penny the required acceleration and it therefore slips.

53. (*a*) 125 cm/s^2 (1·25 m/s^2).
(*b*) 2·5 N.
(*c*) 9·5 N.

54. (*a*) 2·22 m/s^2.
(*b*) 4 N.
(*c*) Also the tension in the string.
(*d*) The metal block has a mass of 0·51 kg.

55. (*a*) 0·5 m/s^2, $F_1 = 5$ N, $F_2 = 15$ N, $F_3 = 20$ N.
(*b*) 20 N.
(*c*) 10m newtons (m is the mass of the hanging body in kg).
(*d*) (10 m $-$ 20) N.
(*e*) m $= 2·1$ kg.

56. 6·67 m/s^2.

57. 0·6 m/s^2, 18 m/s.

58. 10,360 m/s, 14·4 minutes.

59. Acceleration is constant. Free fall under gravity of different masses.

60. (*a*) Tension in CX and CY $= 5·16$ kg. (Draw Triangle of Forces and measure.)
(*b*) Tension in DX and DY $= 18·1$ kgf ($2T \cos\theta = 10$, where $\theta = 74°$).
(*c*) Tension in AX $=$ Tension in BY $= 5$ kgf.
(*d*) Length has no effect (assuming weightless string and constant g).

61. (*a*) Tension $= 100$ N. The long arms of the triangle are near enough to 10 m. 2 N is represented by 20 cm.
(*b*) The line must sag to provide an upward force balancing the weight of the shirt. So to prevent it sagging would require an infinite force.

7 Newton 3 Conservation of Momentum (pp. 75–96)

Introduction

Changelessness. An introduction to the conservation laws of physics. ($\frac{1}{2}$ period)

Motion. Momentum is introduced as the quantity conserved in all collisions. Experiments 7.1, 7.2 and 7.3 are important. It may be found easier to extract the concept of momentum if the experiment on explosions is done first. The order would then be 7.3, 7.1, 7.2. (7 periods)

Collisions in two dimensions. The use of conservation of momentum is extended. Experiment 7.6 should be demonstrated. (2 periods)

Interaction. Newton's third law is so often misstated that we should give time and plenty of discussion to this topic. Experiments 7.8, 7.9 and 7.10 should be done. (3 periods)

Optional Extras. (4 periods)

Experimental Work

***Experiment* 7.1.** This experiment is simple to perform provided that the slope is friction compensated with care before taking measurements. It can be done on a flat board. Only a small piece of tape before and after the collision is required.

***Experiment* 7.2.** Again friction compensation is important. To prevent inelastic collision, the first trolley should not be pushed violently. When running two tapes through the same timer, use fresh carbon paper discs to ensure that clear dots are obtained. Pin the discs lightly to the supporting block so that they turn freely when the tape is pulled through. Fair results are obtained using a level board.

***Experiment* 7.3.** The same remarks as were made above in Experiment 7.2 apply. In this case the plane should be level as it is impossible to friction compensate for trolleys running in opposite directions.

***Demonstration* 7.4.** (See Demonstration 5.7 for notes on the air track.)

Practice is again necessary before performing in front of a class. The frequency of strobing the camera or the light has to be adjusted to the velocities involved, so that the intervals between images of the straw are a convenient distance apart. It is recommended that the incident vehicle is given a gentle push and a flash frequency of about 1,000 per minute is tried at first.

***Demonstration* 7.5.** For notes about the use of air pistols in the laboratory, see Nuffield *Physics Teachers' Guide* 4, p. 124. This experiment may be done using strobe photography to measure the velocity of the vehicle after the collision.

***Demonstration* 7.6.** (See Demonstration 5.8 for notes on the use of this apparatus.) It will be found to be easier to project the incident puck if a device such as the Rugby impeller (Philip Harris Ltd) is used. This enables the experimenter to send the puck at a controlled speed in a fairly precisely determined direction and saves time.

***Demonstration* 7.8.** As an alternative method, a pupil may stand on a small pram, or similar trolley, and throw, in turn, a medicine ball, a football and then nothing. Trolleys shown in Fig. 148 in the text would be very suitable.

***Project* 7.9.** (*c*) The bottle must not have a screw stopper, but one held by friction.

***Project* 7.10.** This might be usefully compared with the Wig-wag machine, Experiment 5.4, both with the load on the tray and with it out of contact with the tray.

ANSWERS TO QUESTIONS

1. Kinetic energy.
2. Heat.
3. See Book One, Chapter 13.
4. Hooke's law.
5. Resistance.
6. (*a*) No.
(*b*) The same in magnitude but opposite in direction.
7. (*a*) $m=1{\cdot}5$ kg. $[1\times 2=(1+m)\times 0{\cdot}8.]$
(*b*) Frictional force changes on increasing the mass. The extra mass must be dropped very gently on the moving mass. It will have to acquire K.E.
8. The first ball transfers momentum to the second and, itself,

travels forward slowly. The collision is very nearly perfectly elastic. In a perfectly elastic condition the second ball would move forward with the original velocity of the first and the first would stop.

9. (*a*) Before $2{\cdot}6 \times 10^{-1}$ kg m/s, after $2{\cdot}52 \times 10^{-1}$ kg m/s. Left to right.

(*b*) Before $1{\cdot}64 \times 10^{-1}$ kg m/s, after $1{\cdot}60 \times 10^{-1}$ kg m/s.

10. It is transferred to the Earth.

11. Because forces acting on bodies tend to change their momentum.

12. At a point which divides the distance separating the trolleys in the ratio 1:3 and which is nearer the three trolleys, i.e. the three trolleys move 25 cm.

The same force acts for the same time on both sets of trolleys. They therefore receive the same momentum. Hence the triple mass has $\frac{1}{3}$ the velocity of the single mass at all times.

13. The trolley moves to the right. It then stops when Jill jumps on. Because Jack takes away the same momentum to the left as Jill returns to it.

14. (*a*) The small one.

(*b*) They will have equal but opposite momenta.

15. 7·2 m/s.

16. Velocity decreased to 4 m/s.

17. 45 m/s.

18. 1·0 m/s, very nearly.

19. 98 m/s.

20. $6{\cdot}68 \times 10^{-27}$ kg since $4 \times 1{\cdot}67 = 6{\cdot}68$. An alpha particle.

21. 7·2 seconds.

22. (*a*) 5 m/s^2, (*b*) 20 m/s, (*c*) 66·7 mi/h.

23. Yes.

24. Yes.

25. Yes. The Earth would get momentum downwards equal to that of the waiter upwards.

26. The pressure excess in the balloon over atmospheric blows air out of the balloon. The balloon moves in the opposite direction to the air blast so that the total momentum of balloon and air remains zero.

27. (*a*) The pull (west) of the tension in the rope.

(*b*) The anticlockwise push of the nozzles on the water.

(*c*) The gravitational pull upward of the parachutist on the Earth.

(*d*) The pull upward of the satellite on the Earth.

(*e*) The pull downward of the weight of the bag of coal on the coalman.

(*f*) The force (south) of ball on bat (as it reverses the ball's momentum).

28. 10^{-24} m/s^2.

29. (*a*) 3 N, (*b*) 3 N (on A), 4·5 N (on B), (*c*) 3 N to the left, (*d*) 3 N to right, (*e*) 3 N to right, (*f*) 3 N to left.

30. (*a*) The propeller drives water backward and the water exerts an equal force forward on the ship, or the propeller gives water momentum to the rear so the ship is given an equal momentum forward.

(*b*) 'Before the wind'. The wind's momentum is reduced by the sails, so the ship gains forward momentum.

'Into the wind'. The sails deflect the air stream so that it gains backward momentum, thus giving the ship forward momentum.

(*c*) The plane's engine pushes exhaust gases backwards, giving them momentum, and the plane gains equal momentum forward.

(*d*) As in (*c*).

(*e*) The driving wheels rotate and push the Earth backward. The Earth exerts an equal and opposite force on the wheels. (These explanations are based on momentum. There are other ways of looking at these problems.)

31. (*a*) Assuming all the air from the blower is brought to rest by the sails, the forward force on the sails would equal the backward force on the blower. There would be no motion.

(*b*) The backward force on the air emerging from the blower would be countered by an equal forward force on the blower. The boat would move forward.

32. If you exert a force X upward on your laces, they will exert a force X downward on your hands.

33. 5 m/s^2 upwards.

34. 8,000 N. [Force equals rate of change of momentum.]

35. No. The momentum change is fixed at 500 kg m/s. This momentum will be destroyed during impact. The force required depends on the duration of the impact.

36. Inelastic—before: v, after: o.

Elastic—before and after the relative velocities are equal and opposite.

37. Velocity is a vector. In this case the relative velocity changes sign.

38. (*a*) 1 m/s approach, (*b*) 1 m/s separation, (*c*) 0·1 kg m/s before, 0·1 kg m/s after, (*d*) elastic.

39. $\dfrac{\text{Mass of ball} \times \text{velocity}}{\text{Time of impact}}$

40. Distance gone in that time.

41. The velocity of A alone will equal the velocity of A + velocity of B in the second experiment. The masses are the same.

(*a*) 0·5 secs, (*b*) 3·0 m/s, (*c*) 9×10^{-2} kg m/s, (*d*) 9×10^{-2}

N s, (*e*) 6×10^4 m/s^2, (*f*) $1{\cdot}8 \times 10^3$ N, (*g*) 5·83 m/s at an angle $\tan^{-1}0{\cdot}6$ to the vertical.

42. Impulse = 3 kg m/s, force = 200 N.

43. (*a*) 1,500 g, (*b*) the large trolley moves forward with a velocity relative to the bench equal to the original velocity of the small one. The small trolley remains still relative to the bench.

44. (*a*) $5{\cdot}10^3$ N, (*b*) $5{\cdot}10^3$ N upward, (*c*) yes, (*d*) 10 m/s^2, (*e*) 8 m/s, (*f*) $4{\cdot}10^3$ kg m/s, (*g*) (i) no, (ii) no, (iii) equal and opposite, (iv) a point in space initially at rest relative to Earth and ram.

45. $T_1 = 0{\cdot}8$ N, $T_2 = 0{\cdot}4$ N.

46. (*a*) 5 m/s^2, (*b*) 10 m/s, (*c*) 40 N s, (*d*) 40 kg m/s.
N s (impulse) ≡ kg m/s (momentum change).

47. (*a*) retarding force of 360 N, (*b*) as (*a*) but opposite, (*c*) 720 N s.

48. (*a*) 4·67 m/s^2, (*b*) 2·17 m, (*c*) 34·7 m, (*d*) 217 m.

49. (*a*) 100 N, (*b*) 3·75 m/s, (*c*) 2·7 m/s.

50. (*a*) 6 kg m/s, (*b*) 11·4 kg m/s west, (*c*) 11·4 N s east, (*d*) 228 N east, (*e*) 228 N west.

51. (*a*) 10 N s east, (*b*) 10 kg m/s east, (*c*) 500 N east.
(*d*) If the ball were kicked horizontally along a frictionless surface the displacement would be 60 m (east).

If it were kicked horizontally from the edge of a cliff the displacement would be $\sqrt{60^2+45^2}$ m = 75 m (east) at an angle of $\tan^{-1}0{\cdot}75$ below the horizontal.

If the ball were kicked at an angle to a level surface so that it *landed* after three seconds the horizontal displacement would be 39·5 m (east).

52. (*a*) 10^6 N, (*b*) 1·75 m/s^2. $6{\cdot}7 \times 10^6 - 5{\cdot}7 \times 10^5 \times 10 = 5{\cdot}7 \times 10^5 \times a$

53. They arrive together. The boy pulls, increases the tension in the rope, and the increase in tension acts on both boy and girl. They have the same mass and are acted upon by the same unbalanced force. They both move from rest with the same upward acceleration.

54. 1 m/s, (*a*) increased, (*b*) not affected.

8 More Work (pp. 96–119)

Introduction

This chapter pulls together the mechanics section of the syllabus partly by more rigid definition of some of the ideas put forward earlier, and to a greater extent by a very large number of numerical questions involving moments, mechanical advantage, velocity ratio, efficiency, power, the two main forms in which mechanical energy appears, conservation of energy, and conservation of momentum.

S.I. units are used throughout. It is advisable to keep to this system without any numerical references to f.p.s. or even c.g.s. systems. Those pupils who are good enough to go on to further work in physics will readily learn to work in more than one system.

The choice of question to be set, for homework for example, will depend on the class standard. The choice of questions should be from all parts of the chapter. With a good class it might be possible to set some of the additional problems (No. 88 onward) early on. If they are answered correctly, it would save a lot of time in doing questions of a more obvious nature.

Experimental Work

Project **8.1.** A little ingenuity will produce a variety of set-ups. They should be left to do this without help, for in trying they will soon let the teacher see where their errors lie. Efficiencies will be very low.

Experiment **8.2.** The results from this experiment yield many sociological examples. If your efficiency is poor, then a high percentage increase is possible. So suspect any firm that has a sudden rise in productivity—it may have been very inefficient before!

Let them do this experiment with weak string, and encourage them to get as high an efficiency as possible. The machine breaks down. So don't push machines, or work people, or pupils too hard!

Experiment **8.3.** This is a *must.*

Experiment **8.4.** (*a*) Most of the model engines used are very inefficient and the power output is very disappointing. There is no condenser, so a great waste of energy. (See Project 10.7 for a more complete experiment.)

(*b*) This depends on the type of bicycle dynamo fitted. Efficiency

again will be very low, particularly so with the dynamos driven by friction of the tyres. For (ii) turn the bicycle upside down and use a spring balance to estimate the force needed to turn the pedals. From this calculate the work done per second as the pedals are turned. This ought, perhaps, to have been 'Project 8.4'.

***Experiment* 8.5.** This sometimes becomes rather confusing in practice. It pays to record the increase in the length of the spring and the increase in force, both from some arbitrary starting position which has the spring already in tension. This gets rid of difficulties about graphs that don't go through the origin, i.e. it eliminates 'end conditions'. Refer back to pp. 33, 34 where distance d is represented by an area. This is a difficult concept, and much time has to be given to it. Most pupils do not have a complete understanding of how, in this case, the area under the graph can represent the work done. It is a good opportunity to introduce the ideas on which calculus is based.

***Project* 8.6.** This must be left for the pupils to find out at home, unless an automatic watch is brought in to the class for examination.

***Demonstration* 8.7.** The timing system is referred to in Demonstration 5.7(*b*). This experiment depends very much on the careful choice from the supply of elastic threads for trolley experiments, of those that behave exactly alike, in a situation where a slight error in displacement makes very great difference in the forces applied (Fig. 114).

***Project* 8.8.** An ORP 12 photo-conductive cell and a quartz-halide lamp will work here.

Note on 'Mathematics': When we speak of 'mathematics' we must be very careful to find out what is being taught in the school. The syllabus is changing even more radically than our Physics syllabus, the language and symbols used are quite different, and a class will be less ready to give one numerical answer to a problem. It is to be hoped that their powers of reasoning will be improved, that they will tackle new ideas with imagination.

When we have established that $F \propto a$ and $a \propto \frac{1}{m}$ by experiment, they should be able then to look at $F \propto ma$ and by inspection appreciate that it contains $F \propto a$ (m constant) and $a \propto \frac{1}{m}$ (F constant).

Similarly, $PV=T$ can be appreciated as including $PV=$constant (T constant), $V \propto T$ (P constant), etc. without moving to the full statement by a mathematical process.

In the case under consideration here, the establishment of

$KE=\frac{1}{2}mv^2$, more discussion of the conservation of energy will be required.

It is very important to emphasise that in the mathematics that gives $F\times d=\frac{1}{2}mv^2$ we are assuming that all the work done by the force is then residing in the moving mass, i.e. this involves an acceptance of the conservation of energy. We must then avoid, as *P.I.F.* has done, any attempt ever to use $\frac{1}{2}mv^2$ as a measure of the K.E. of a body in order to *verify* the law of conservation of energy.

It is worthwhile going back to the wheel and axle (Book One, p. 115), calculated as a lever on balance (as in Example 26) and then considering a very small increase in E to, say, E'. This will cause movement. Calculate the work in and work out. As this increased value E' approaches E, i.e. as the design improves so the loss of energy reduces to zero. This is enough to suggest that energy is conserved. As a further illustration use the music-hall turn of one acrobat jumping down on to a see-saw and sending another flying up. Allow a 'Super Ball' (Woolworths) to bounce; the better the ball the nearer to its starting position does it rise. Swing a pendulum; the better its design the longer it continues with little reduction in width of arc (Project 8.9). So the law becomes an expression of our common experience. In our present state of science we are forcing all experimental results into the orbit of this law. It may of course be that succeeding generations will look back upon us as we look upon those who persisted as phlogistonists in the face of new evidence.

***Project* 8.9.** This is a really stern test of our belief in the conservation law. Fear, instinct, whatever it is, nearly always overcomes rational belief and as the ball comes back up it is almost impossible not to draw back. (The warning is important. Let the experimenter be the operator!)

***Project* 8.10.** Add here another series of interesting experimental projects. Let a good trolley, a solid cylinder, a hollow cylinder and a sphere of the same radius run down a slope and get predictions as to which is fastest, before the experiment.

Run various balls down V grooves of same inclination, having predicted the order.

The idea of K.E. being translational and rotational is more important than the slight reference given in this project. No numerical calculations are required, simply a consideration of what is happening to the individual particles of whatever is moving.

***Project* 8.11.** This becomes even more mystifying if the rails are pushed parallel when the cone has reached the 'top' causing it to run down to the 'bottom' again. Perpetual motion? (Note the famous 'Electric Brae' on the Ayrshire coast road is about 9 ft higher at the

bottom than at the top. The land configuration suggests the road goes downhill, but it actually moves up a valley to cross at a higher level.)

Project **8.12.** This is really a corollary from 8.7. We give the pennies energy when they are given velocity, and instead of their being stopped by different forces in the same distance, they are stopped by the same force (friction) in different distances. So $\frac{1}{2}mv^2 = Fd$ will solve this.

Project **8.13.** This has plenty of suggestions for approach.

Project **8.14.** Note all the efforts are more easily considered if the strings are parallel. Fig. 197 is referred to and discussed in the answer to question 23. Fig. 196 gives a lot of difficulty. There is really nothing holding up the pulley at the effort, so it will just run down. If an effort is put on, the result is $2E$ down on pulley and $1E$ up, so it always goes down. When it gets down it can't go any lower, and even if it didn't jam completely, any rise in L would only allow E to fall as much.

Project **8.15.** This has a good enough hint towards the wheel and axle.

Project **8.16.** The calculation is similar to that in question 51, Chapter 6. From the tape the deceleration is found. Using $F = ma$ the frictional force may then be calculated.

The original K.E. may be found by estimating the original velocity and using $\frac{1}{2}mv^2$ or by assuming that the frictional force is constant and finding the distance moved before the block comes to rest. The energy is then found from Fd.

Project **8.17.** This depends on the chosen apparatus.

ANSWERS TO QUESTIONS

Take $g = 10$ m/s^2 or 10 N/kg.

1. Mechanical work—potential energy, kinetic energy of translation and rotation; energy in strained material, springs, etc., in compressed air; energy in foods and fuels appearing as heat of chemical action; heat energy, latent heat; light, electromagnetic radiant energy; sound; atomic energy; electrical energy.

2. All except nuclear energy. The Earth's residual heat may depend on the formation of the Earth from the substance of the Sun. During photosynthesis, the Sun's energy is used in forming fuel and food, its rays evaporate water to produce rain for hydro power.

3. It is dissipated as heat, usually radiated into space.

4. Radiant energy from the Sun; water movements caused mainly

by the interaction of the Earth and the Moon's gravitational fields, but with the Sun's field also operating; unequal heating of the atmosphere by the Sun; evaporation by the Sun's rays of water which subsequently condenses and falls under gravity.

5. (*a*) Microphones, (*b*) loudspeakers, headphones, (*c*) exposure meters, solar cells, (*d*) light bulbs and tubes, (*e*) batteries, (*f*) steam engines, (*g*) electric motors.

6. An electromagnet uses energy to hold up an iron block. But since it does no work once the block is raised, it will dissipate energy as heat. No energy is transferred when the permanent magnet is *holding* the block.

7. The woman does work in lifting up the poodle. The satellite does no work as it revolves in orbit. Its motion is perpendicular to the only force—gravity—which is acting. Atlas does no work if he just holds up the Earth in theory, but food and oxygen must be given to muscle to keep it working—this energy again appearing mainly as heat. This is similar to the electromagnet situation. (See *Nuffield Teachers' Guide* 1, p. 37–9.)

8/9. Not always, for if there is no frictional force to be overcome no work will be done.

10. No.

11. No.

12. Force $= 6 \times 10^3$ N. Total distance $= 4 \times 200$ m.
Work $6 \times 10^3 \times 4 \times 200$ joules $= 4{\cdot}8 \times 10^6$ joules.

13. The force to stretch thick rubber is greater than the force to stretch thin rubber, therefore the work done to extend the thick rubber is greater than the work to extend the thin rubber over the same distance.

The same force would extend the thin one more than the thick one.

14. As a first guess we can say the force is at right angles to the motion so no work is done against the force. But remember elliptical orbits and tidal effects make this just a guess at the answer. We cannot even consider the Earth and Moon together as a unit, with only internal energy being redistributed.

15. $f \times D$ is the work done *by* f and $F \times d$ is the work done *against* F.

16. Mechanical advantage.

17. Velocity ratio. (N.B. the word 'velocity' reminds us that the time of the two actions is the same; they are simultaneous.)

18. Because some energy is lost in heat, or friction, or in moving the parts of the machine, or in sound.

19. Efficiency $= \dfrac{L \times d_l}{E \times d_e} = \dfrac{L}{E} \div \dfrac{d_e}{d_l} =$ M.A. $\div$ V.R.

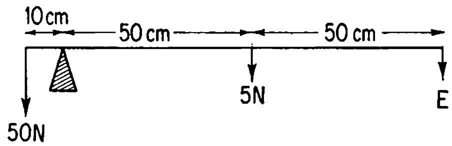
20. $X = 2$ m, since the bar is uniform.
$Y = 4$ kgf, since the distances from the pivot are both 1 m.
$Z = 4 + 4$ kgf $= 8$ kgf $= 8 \times 10$ N.

You could regain balance by adding 4 kgf at end, or by removing existing 4 kgf.

21. Hang retort stand by a string, adjust string until rod is horizontal. This gives position of the centre of gravity of rod, G. Hang 1 kg mass at end of rod A and move suspension to restore balance at O. Measure distances AO and OG. $m \times GO = 1 \times AO$. Hence m. This gives weight or force at G. Acceleration due to gravity is constant, so m can be expressed in mass units.

22. There is an error here (in 1966 printing). The cross sections should be given, e.g. 10 cm² and 2 cm², not the volumes. Given this change then a movement down of 5 cm of the 2 cm² syringe will displace 10 cm³ of liquid and so raise the 10 cm² syringe 1 cm, i.e. V.R. = 5. To find M.A. put a load on 10 cm² side and find load on other side that just raises the heavier load. This then gives Efficiency from $\frac{\text{M.A.}}{\text{V.R.}}$

23. The length of the bar was unfortunately omitted from the problem. It should have been given as 110 cm. The bar is not uniform.



By moments

$$10 \times 50 = 50 \times 5 + 100E$$
$$\therefore \quad E = 2{\cdot}5 \text{ newtons}$$

$$\text{V.R.} = 10 \text{ as before}$$
$$\text{M.A.} = \frac{50}{2{\cdot}5} = 20$$
$$\therefore \quad \text{Efficiency} = 200\,\%.$$

Alternatively we may consider the work done. The rod's centre of gravity will fall 0·05 m doing $(5 \times 0{\cdot}05)$ joules $= 0{\cdot}25$ joules of work. But the total work done $= (50 \times 0{\cdot}01)$ joules $= 0{\cdot}5$ joules. So the work done by the effort $= 0{\cdot}5 - 0{\cdot}25$ joules $= 0{\cdot}25$ joules. The effort required is therefore $\frac{0{\cdot}25}{0{\cdot}1}$ newtons $= 2{\cdot}5$ newtons. The efficiency is again apparently 200 %.

In dealing with efficiency, a whole cycle of operations must be considered. This machine is not ready to lift another load until it has been lifted up itself, requiring 0·25 joules of work to do this. So its overall efficiency is still 100 % assuming there are no losses.

Compare the system of pulleys in *P.I.F. Book Three*, Fig. 197. The weight of one pulley *assists* the effort and the load could actually be

raised without any effort, i.e. $\infty\%$ efficiency, if the load were less than the weight of the pulley! But to complete the cycle the pulley has to be raised again to its original position.

24. Much force is required to cut the tin. Tailors have long lengths of cloth to cut and little force is required.

25. Balance the broomstick on a string. Hang 1 lb of butter at one end, and hang the bag of apples at a point such that the beam stays balanced. Measure the distances from the butter to the point of suspension, and from apples to the point of suspension.

26. For a balance $L\times r=E\times R$. So a little extra on E will cause L to rise. The wheel and axle has the great advantage over the lever in that r and R remain the same throughout. In the ordinary levers, motion ceases when the lever swings to the vertical position.

27. (*a*) By moments $F\times 1{\cdot}00=4\times 0{\cdot}60+6\times 0{\cdot}50=5{\cdot}40$.
$\therefore$ Force is just over 5·4 kgf (54 N).
(*b*) Gain in P.E. $=(4\times 10\times 0{\cdot}06)$ joules $=2{\cdot}4$ joules.
(*c*) Edge of door rises 10 cm.
(*d*) $\dfrac{L}{E}=\dfrac{4}{5{\cdot}4}=0{\cdot}74$.

28. From moments the bigger the distance from the wheel axle the greater the torque exerted by the friction pad. From energy considerations, the bigger radius the greater the distance over which the frictional resistance is overcome. Hence greater radius of disc on sports car. The brakes get hot because the energy of the car in motion is being lost as mechanical energy and transformed into heat.

29. (*a*) V.R. $=3$ (Ratio of distance effort moves over distance load is raised against gravity).
(*b*) M.A. $=\dfrac{50\times 10}{300}=1{\cdot}67$.
(*c*) Efficiency $=\left(\dfrac{1{\cdot}67}{3}\times\dfrac{100}{1}\right)\%=55\%$ or $=\dfrac{50\times 10\times 10.}{300\times 30}$
The latter is better, as it uses the true definition.

Efficiency increases if wheels or rollers are used because there is less movement of surface over surface, i.e. less friction. Using wheels or rollers most losses are in lifting the actual parts for any rubbing surfaces are made specially smooth and are well lubricated.

30. (*a*) Work done by effort $=300\times 4=1{,}200$ joules.
(*b*) P.E. gained $=800\times 1=800$ joules.
(*c*) Because energy is lost overcoming friction between block and board.
(*d*)
$$\text{M.A.}=\frac{800}{300}=2{\cdot}67$$
$$\text{V.R.}=4$$
$$\text{Efficiency}=\frac{800}{1200}\times\frac{100}{1}\%=67\%$$

$$\left[\text{or} = \frac{2{\cdot}67}{4} \times \frac{100}{1}\%.\right]$$

31. For very fine adjustment. The very high V.R. ensures that a rotation of the screw gives a very slight up or down movement of the screw. But fine threads cannot stand very heavy loads.

32. $\text{V.R.} = \dfrac{\text{Distance effort moves}}{\text{Distance load is raised}} = \dfrac{2\pi r}{\text{pitch}} = \dfrac{2 \times 22 \times 0{\cdot}14}{7 \times 0{\cdot}002} = 440.$

Efficiency is often as low as 12%. (Watch your knuckles!)

33. V.R. = 4. If the load rises 1 metre then each string between the blocks must shorten by 1 m, so the effort will fall 4 m.

34. 5 kg. Ignore the weight of the pulley.

(*a*) The force will increase, to give the body its acceleration.

(*b*) The reading will stay steady if the load is raised at constant speed.

35. $\text{M.A.} = \dfrac{3 \times 10^3}{70 \times 10} = \dfrac{30}{7}$. V.R. must be greater, i.e. 5 is minimum.

(This *assumes* the man is dangling on the rope. He can exert a force greater than his own weight if he takes the effort rope round a pulley attached to the floor and pulls upward—see any sailing boat.)

Choose a block and tackle with 5 pulleys, V.R. = 5.

$$\text{M.A.} = \frac{30}{7},\ \text{V.R.} = 5.$$

Then $\text{Efficiency} = \dfrac{30}{7 \times 5} \times \dfrac{100}{1} = 86\%.$

36. (*a*) Because 4 × effort is pulling the car, and in (*b*) only 3 × effort pulls car.

V.R. in (*a*) = 4, V.R. in (*b*) = 3.

37.

L	10	30	60	100
E	1·9	3·1	5	7·5
$\text{M.A.} = \dfrac{L}{E}$	5·3	9·7	12·20	13·3

Since V.R. is a constant, the *shape* of Efficiency/Load will be same as M.A./Load. The value of the M.A. is levelling off at about 14 so the V.R. must be about 28 or 30 for an efficiency of about 50%.

38. From the work done against the frictional force between the chisel and the stone.

39. The speed of the wheel and the pressure on the chisel.

40. A force of 2 N, due to friction, acting in the direction of the 11 N force.

41. Force being overcome 80 N. Distance moved against this force per second = circumference × n = 0·6 × 10 m = 6 m. Then work done

per second $=80\times 6$ watts $=480$ watts. Input power (watts) = P.D. (volts) × current (amperes). 240×3 watts $=720$ watts. ∴ Efficiency $=\frac{480}{720}\times\frac{100}{1}=67\%$.

42. No, for the son only claims he could, he doesn't necessarily do it! But if we agree that each could have mowed the lawn when it was exactly in the same condition, then each would do the same work, therefore the son's power would be greater. (But the father's 'power' would be greater if he got his son to do the job at all!)

43. Force overcome $1{\cdot}5\times 10^3\times 10$ N.
Distance moved 2 m.
Time 20 s.

∴ Power = work done per second $=\dfrac{1{\cdot}5\times 10^4\times 2}{20}$ watts $=1{\cdot}5\times 10^3$ watts.

44. Work available per second $=7\times 10^6\times 10\times 50$
$=3{\cdot}5\times 10^9$ watts $=3{,}500$ megawatts.

45. Available power $=50\times 10^3$ watts.
Force to be overcome $=2\times 10^3\times 10$ N.

Distance moved per second $=\dfrac{50\times 10^3}{2\times 10^3\times 10}=2{\cdot}5$ m/s.

46. Yes, but it will raise it at only $\frac{1}{5}$ of the speed.

47. Available power $=150\times 10^3$ watts. Distance through which force is overcome per second $=50$ m. Force to be overcome $=\dfrac{150\times 10^3}{50}$
$=3\times 10^3$ N $=3\times 10^2$ kgf.
Since there is no acceleration all this force must be overcoming friction.

48. Yes, when it falls down again. Think of the clowns in the circus who drop on to see-saws and send their partners up in the air.

49. It falls because the gravitational pull has now no opposition from the rigid shelf, and so it loses potential energy. This energy is transformed into heat.

50. For modelling, for insulation.

51. Pneumatic tools use compressed air for drills, etc. You can see the compressors working at the roadside, or in quarries. No bad fumes come from the exhaust from the drills, so they are used in tunnels, and under water. Used in sprays for insecticides, etc.

52. Work has been done against the intermolecular forces of the spring and has moved the molecules into new positions where they are again relatively stable. This property of ductility is shown mostly in metals. The work done usually appears as heat.

53. Using work = area under graph: Using aver. force × distance.
(*a*) Work $=\frac{1}{2}\times 2\times 2=0{\cdot}2$ joules: (*a*) $=(\frac{1}{2}\times 2)\times 0{\cdot}2=0{\cdot}2$ joules

(*b*) Work $=\frac{1}{2}\times 3\times 0{\cdot}3=0{\cdot}45$ joules : (*b*) $=(\frac{1}{2}\times 3)\times{\cdot}3=0{\cdot}45$ joules

i.e. stored P.E. $=0{\cdot}45$ joules.

54. (*a*) When a magnet in a scrap yard holds up scrap iron. When two magnets are held N to N and S to S.

(*b*) In a capacitor, in clouds before a lightning flash, in Van de Graaf generator.

(*c*) Weights in a clock, water in a hydro scheme, in a pile driver.

55. P.E. = Force × distance force is overcome $=70\times 10\times 2$
$=1{,}400$ joules.

This wrongly assumes he has raised his C. of G. by 2 metres. He really rolls over the high jump bar and only lifts his C. of G. about 1 metre.

56. C. of G. is 3 cm above ground. When toppled C. of G. is raised to 5 cm. ∴ Height raised $=2$ cm $=0{\cdot}02$ m $=2\times 10^{-2}$ m.

$$\text{Total force overcome} = 6\times 8\times 8\times 8\times 10^{-3}\ \text{kgf}$$
$$= 6\times 8\times 8\times 8\times 10^{-2}\ \text{N}$$
$$\therefore\ \text{Energy required} = 6\times 8\times 8\times 8\times 10^{-2}\times 2\times 10^{-2}\ \text{joules}$$
$$= 0{\cdot}6144\ \text{joules.}$$

57. Ball has K.E., this is converted to P.E. of deformation. When the ball is at rest all the energy is P.E. This energy is then used up in giving the body K.E. again, as the original shape of the ball is restored. The rebound velocity $<$ initial velocity and some of the energy is now heat. (Remember we assume wrongly that the wall remains stationary. The ball's original momentum must be shared out between the ball's and the Earth's movement subsequent to the impact. We *must* allow for this when considering the conservation of momentum, but can ignore it in energy conservation since the velocity changes in the Earth are very small and energy $\propto$ velocity^2.)

In terms of molecules, the molecular distances are altered by the first molecules in 'contact' with the wall being slowed up. So repulsive forces are set up in the ball. In the normal state the molecular distance is that for which attractive and repulsive molecular forces balance one another, and any modification of this distance produces restoring forces.

58. The force of friction which was opposing motion has been overcome, and the work done against friction will again appear as heat. You can imagine that the irregularities of the surface pulled the molecules out of position until the restoring forces become so great that the molecules tended to return to their original positions. But of course they gained K.E. and so tended to oscillate more violently about their position of stability, i.e. became hotter.

59. (*a*) Forces are the same.

(*b*) Each gains same momentum since forces and times of

action of the forces are the same. Force $\propto$ rate of change of momentum.

(*c*) m will move farther than M.

(*d*) m will move faster than M.

(*e*) m has more K.E. since this is proportional to the square of the velocity.

$$(mv = MV \text{ so } v = \frac{M}{m}V \quad \therefore \tfrac{1}{2}mv^2 = \tfrac{1}{2}m(\frac{MV}{m})^2 = \tfrac{1}{2}MV^2.\frac{M}{m}.)$$

60. The stretched elastic stores the same energy in each case. The resistive force of the plasticine is the same in each case.

$\therefore$ the distance the needle penetrates is the same.

61. $\tfrac{1}{2}mv^2 = \tfrac{1}{2}.\ 0{\cdot}17 \times 20 \times 20 = 34$ joules.

62. (*a*) It is stored as potential energy.

(*b*) It appears as kinetic energy.

(*c*) It appears as heat.

63. P.E. $= 50 \times 10 \times 5 = 2{\cdot}5 \times 10^3$ joules.

$\therefore$ K.E. $= 2{\cdot}5 \times 10^3$ joules just before striking post.

$\therefore$ $\tfrac{1}{2}mv^2 = 2{\cdot}5 \times 10^3$ joules

$\therefore$ $v = \sqrt{\dfrac{2{\cdot}5 \times 10^3 \times 2}{50}} = 10$ m/s.

or simply $v^2 = 2gh$ gives $v = \sqrt{2 \times 10 \times 5} = 10$ m/s and $\tfrac{1}{2}mv^2 = \tfrac{1}{2} \times 50 \times 10^2 = 2{\cdot}5 \times 10^3$ joules.

64. $\tfrac{1}{2} \times 10^9(10^2 - 5^2) = 3{\cdot}75 \times 10^9$ joules.

65. (*a*) True, in theory if there are no other masses anywhere.

(*b*) False in Newtonian physics.

(*c*) This depends on the definition of density. Mass/volume remains constant.

(*d*) If we say the weight of a body is measured by the pull of the *Earth's* gravitational field, then the Earth has no weight. But if we say the weight of a body is measured by the resultant force on it due to all the material of the Universe then the Earth has weight due to the pull of the other bodies on it.

(*e*) True. It is a momentum reaction.

(*f*) False. It increases maybe the force you can exert, but any benefit of force is lost in the reduction of the distance moved.

(*g*) True. More mass would be required to stretch the spring since the gravitational field is reduced.

(*h*) False. But very seldom does a force act without producing some kind of distortion, using up energy.

(*i*) False. Air resistance acts differently on different bodies. The distance from the centre of attraction affects the motion.

66. P.E. at A $=m.10.60$ P.E. at B $=m.10.15$

Loss of P.E. $=m.10.45$

This is all changed to K.E.

$\therefore \quad \frac{1}{2}mv^2 = m \times 10 \times 45$

$\therefore \quad v = \sqrt{2 \times 10 \times 45}$

$= 30$ m/s.

N.B. This is a *speed* not a velocity, as any path from A to B gives the same numerical value and this speed is the same in value as for free fall.

67. Because the energy to be used up in the crash to bring the cars to rest is proportional to (velocity)^2.

68. Estimated mass of boy $= 50$ kg (8 stone)

Velocity $= 6$ m/s (c. 12 mi/h)

K.E. $= \frac{1}{2} \times 50 \times 6^2 = 900$ joules.

69. (*a*) Not true—this depends on time of change.

(*b*) True.

(*c*) Wrong—K.E. is quadrupled.

(*d*) Wrong—this has nothing to do with P.E.

70. (*a*) (Assume misprint of 113 for 114.) Unbalanced force $= 114 - 50 = 64$ N.

(*b*) Acceleration $= \frac{64}{40} = 1{\cdot}6$ m/s^2.

(*c*) $d = \frac{1}{2}\,at^2 = \frac{1}{2} \times 1{\cdot}6 \times 4 = 3{\cdot}2$ m.

(*d*) $v = at = 1{\cdot}6 \times 2 = 3{\cdot}2$ m/s.

(*e*) Energy supplied is $114 \times 3{\cdot}2$ joules $= 364{\cdot}8$ joules.

(*f*) Energy gained by box $= 64 \times 3{\cdot}2 = 204{\cdot}8$ joules.

(*g*) Energy overcoming friction $= 50 \times 3{\cdot}2 = 160$ joules.

(*h*) Their sum must be the same as the total energy supplied.

71. (*a*) 9 kg.

(*b*) $a = \frac{36}{9} = 4$ m/s^2.

(*c*) Force on Q $= 5 \times 4 = 20$ N.

(*d*) The molecular repulsion between P and Q.

(*e*) The reaction is a force from Q to P $= 20$ N in direction Q $\rightarrow$ P.

(*f*) Unbalanced force on P $= 36 - 20 = 16$ N.

(*g*) Velocity $= 4 \times 3 = 12$ m/s.

$K.E_P. = \frac{1}{2} \times 4 \times 12^2 = 288$ joules (or 16×18).

$K.E_Q. = \frac{1}{2} \times 5 \times 12^2 = 360$ joules (or 20×18).

(*h*) $d = \frac{1}{2}at^2 = \frac{1}{2} \times 4 \times 3^2 = 18$ m.

(*i*) Q would continue to move at 12 m/s.

(*j*) $36 - 4 - 5 = 27$ N.

(*k*) 9 kg.

(*l*) $27 = 9a \quad \therefore a = 3$ m/s.

(*m*) Horizontal force causing acceleration $= 5 \times 3$ N.

Frictional force to be overcome $=5$ N
$\therefore$ Total force on Q $=20$ N.

(*n*) The residue of the 36 N not used in accelerating P (12 N) and in overcoming the friction due to P (4 N).

(*o*) 20 N from Q to P.

(*p*) 12 N $(36-20-4)$.

(*q*) Velocity $=3\times 3=9$ m/s.
K.E$_{P}$. $=\frac{1}{2}\times 4\times 9^2=162$ joules
K.E$_{Q}$. $=\frac{1}{2}\times 5\times 9^2=202{\cdot}5$ joules.

(*r*) $S=\frac{1}{2}\times 3\times 3^2=13{\cdot}5$ m.

(*s*) Velocity after first 3 seconds $=9$ m/s
Retarding force is 5 N
$\therefore$ retardation $=1$ m/s^2
$\therefore$ new velocity after 3 seconds $=9-(3\times 1)=6$ m/s.

72. (*a*) These are easiest measured in inches, but this is no use, for calculating energies in any established units. But simply using $\frac{1}{2}mv^2$, unspecified, gives the comparisons required.
K.E. before impact $=\frac{1}{2}.1.\frac{1}{2}^2=\frac{1}{8}$
K.E. after impact $=\frac{1}{2}.2.\frac{1}{4}^2=\frac{1}{16}$

Or velocity before impact $=\dfrac{5\text{ cm}}{0{\cdot}45}=12{\cdot}5$ cm/s

Velocity after impact $=6{\cdot}25$ cm/s
K.E. before $=\frac{1}{2}.1.(12{\cdot}5)^2$ K.E. after $=\frac{1}{2}.2.(6{\cdot}25)^2$
So K.E. not conserved. Energy is used up in deformation.

(*b*) Velocities same, masses same, energies the same. No losses.

(*c*) m_2: velocity before 0·9 m_3: velocity before $-0{\cdot}55$
m_2: velocity after $-0{\cdot}4$ m_3: velocity after 0·35
Total K.E. $=\frac{1}{2}\times 2\times 9^2+\frac{1}{2}\times 3(-0{\cdot}55)^2=0{\cdot}81+0{\cdot}45$
before $=1{\cdot}26$ units.
Total K.E. $=\frac{1}{2}\times 2(-0{\cdot}4)^2+\frac{1}{2}\times 3\times 0{\cdot}35^2=0{\cdot}16+0{\cdot}18$
after $=0{\cdot}34$ units.

(*d*) Requires answers from experiment. There will be a loss in energy due to work done by the bullet penetrating the target.

73. Potential energy due to deformation, or change of state, heat, light, sound, but always eventually heat.

74. Speed is constant, therefore K.E. is same.

75. Momentum is different.

76. Velocity is changed in direction and momentum is a vector quantity.

77–78. There will be a period when the energy is partly P.E.—due to the overcoming of the repulsive forces of the magnets and the subsequent release of this energy. The motion of the moving puck will not be in a straight line during this part of the action.

79. (*a*) Momentum before impact $=10^4\times 4=4\times 10^4$ kg m/s

$\therefore$ momentum after impact $=6\times10^4\times v=4\times10^4$ kg m/s.

(*b*) Velocity after impact $=\dfrac{4\times10^4}{6\times10^4}=0{\cdot}66$ m/s.

(*c*) K.E. before impact $=\frac{1}{2}\times10^4\times4^2 \quad =8\times10^4$ joules

K.E. after impact $=\frac{1}{2}\times6\times10^4\,\dfrac{4^2}{6^2}=\dfrac{8}{6}\times10^4$ joules

$=1{\cdot}33\times10^4$ joules.

(*d*) It is an inelastic collision, so energy is used up.

80. (*a*) K.E. before collision $\frac{1}{2}\times1\times1{\cdot}5^2 \quad \propto 2{\cdot}25$

K.E. before collision $\frac{1}{2}\times1\times1{\cdot}3^2+\frac{1}{2}\times1\times6^2 \propto 1{\cdot}69+{\cdot}36$

$\propto 2{\cdot}15$

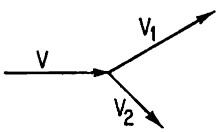
The measures can be done more accurately:

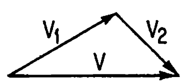
$$\left.\begin{aligned}1{\cdot}5 \text{ becomes } \frac{5{\cdot}8}{4} &= 1{\cdot}45\\ 1{\cdot}3 \text{ becomes } \frac{5{\cdot}05}{4} &= 1{\cdot}26\\ 0{\cdot}6 \text{ becomes } \frac{2{\cdot}4}{4} &= 0{\cdot}6\end{aligned}\right\}\ \text{These give very close agreement for K.E.}$$

The angle is 90°.

This is a condition that holds when equal masses collide elastically. The velocities can then represent the momenta. For the conservation of momentum, using vectors,

$\vec{v}=\vec{v_1}+\vec{v_2}$. Draw the vector triangle.





For conservation of energy $v^2=v_1{}^2+v_2{}^2$; therefore the triangle is right-angled, v_1 being at right angles to v_2.

(*b*) Yes. 'The angle is 90°' is enough evidence if the masses are equal. K.E. is scalar. Readings similar to 80(*a*) give good agreement.

81. Since it is a two-dimensional representation of a three-dimensional action, or rather the plane of the paper is not necessarily the plane of the action, not much can be said. The angle is not obviously right-angled, but nearly so. Assuming it is 90°, we can then say the masses are equal.

82. It seems likely that molecular collisions are elastic. If not, the molecules would slowly slow down, heat would be produced, and the volume would decrease.

83. Speeds can be estimated by measuring the distances travelled between two dots nearest to the $d=1, 2, 3, 4$ positions.

This gives:

v	3	4	5	6
d	1	2	3	4
v^2	9	16	25	36
v^2/d	9	8	8	9

This will be uniform acceleration as expected ($v^2 = 2\ ad$).

84. $F \times S$ is the energy of the extended string.
This will be proportional to K.E. produced, i.e. $\propto v^2$.
So if F is quadrupled, v^2 is quadrupled, i.e. v is doubled.

85. Σmv before impact $= 1 \times 2$ units
$\Sigma(1+M)v$ after impact $= (1+M)\ 0{\cdot}8$ units
$\therefore\ (1+M)0{\cdot}8 = 2 \quad \therefore\ (1+M) = 2{\cdot}5$ kg.
Energy before impact $\frac{1}{2} \times 1 \times 2^2 = 2{\cdot}0$
Energy after impact $\frac{1}{2} \times 2{\cdot}5 \times 0{\cdot}8^2 = 0{\cdot}8$
Therefore loss of energy is $\frac{1{\cdot}2}{2{\cdot}0}\ \% = 60\%$.

86. Velocity attained is given by $v^2 = 2gh$. So the velocity will be increased to $\sqrt{2}v$ by doubling the height. Downward fall is same in both after leaving the table $\therefore$ d will increase to $\sqrt{2}d$.

87. P.E. from plunger is constant. Then $\frac{1}{2}mv^2$ will be a constant value. So if mass is doubled, v^2 is halved, i.e. the new velocity is $\sqrt{\frac{v}{2}}$.

88. Yes—if he can balance on the board. He can easily exert a force greater than his own weight; here he only requires to exert a force half his own weight.

89. A very high V.R. The efficiency could be high for reverse worms can now be made, e.g. for centrifuges and they produce little frictional loss. But in general this arrangement has a low efficiency because of frictional forces between badly designed screws and pinion teeth, and because the pinion teeth simply catch on to the worm like a ratchet.

90. $F = 10$ N Distance moved per second $= 0{\cdot}3 \times 3$ m/s.
$\therefore$ Power $= 10 \times 0{\cdot}3 \times 3 = 9$ watts.
Some energy goes into K.E. of the material of the mixture, some to break it up physically, some to heat.

91. (*a*) Force to raise locomotive vertically $= 10^5 \times 10$ N.

Distance raised vertically per second $= \dfrac{10 \times 2}{100}$ m/s.

Then power is $\dfrac{10^5 \times 10 \times 10 \times 2}{100} = 2 \times 10^5$ watts.

(*b*) Power to overcome frictional forces = frictional force $\times$ distance moved against friction per second.
$= 3 \times 10^3 \times 10 = 30 \times 10^3$ watts $= 3 \times 10^4$ watts.
$\therefore$ Total power $= 2 \times 10^5 + {\cdot}3 \times 10^5 = 2{\cdot}3 \times 10^5$ watts.

92. Energy $= 60 \times 10 \times 600 = 3{\cdot}6 \times 10^5$ joules $= \frac{1}{10}$ kilowatt hour. (1 kilowatt hour $= 1{,}000 \times 60 \times 60 = 3{\cdot}6 \times 10^6$ joules.)

Cost of the energy at 2d per kilowatt hour $=0{\cdot}2$d.

93. Power available 2×10^6 watts $=$ Force $\times$ velocity $=$ Force $\times 200$

$\therefore$ Force $=10^4$ N $=10^3$ kgf.

Since there is no acceleration this is the force required to overcome friction. The work done is proportional to both the time and the distance since v is constant.

94. Force down plane $=$ frictional resistance since there is no acceleration.

$$\therefore \text{ Frictional resistance} = \frac{4\times10^5\times10\times1}{200}\text{ N} = 2\times10^4\text{ N.}$$

This remains the same on the level track so to move the train at 20 m/s steadily the rate of doing work (power) $=2\times10^4\times20$ watts $=4\times10^5$ watts $=400$ kilowatts.

95. If the tyres are soft more heat is generated by the constant flexure of the walls of the tyres. The car will therefore use more power to maintain the same speed.

96. If the man runs up the escalator at a constant speed the average force exerted on the steps will be equal to his weight. The escalator motor will therefore work at the same rate whether the man is standing or running at a constant speed. However, he will get to the top in a shorter time if he runs up the escalator so the work done by the motor will be less. The man himself does the extra work so that the *total* work done is the same whether he stands or runs up the escalator at a constant speed.

97. (*a*) K.E. $=\frac{1}{2}mv^2=\frac{1}{2}\times170\times(30)^2=76{\cdot}5$ joules.

(*b*) K.E. $=\frac{1}{2}mv^2=\frac{1}{2}\times9\times10^{-31}\times(3\times10^7)^2=40{\cdot}5\times10^{-17}$
$=4{\cdot}05\times10^{-16}$ joules.

98. Energy to be used up is $\frac{1}{2}mv^2$. So if damage is same and masses are in ration 4:1 then the ratio of the velocities squared is 1:4, i.e. velocity of heavy car is half that of light car so its likely speed is 20 miles per hour.

99. If the second trolley has the same mass as the first the momentum is doubled, so velocity is doubled, and energy is quadrupled. If the resistive force of the plasticine is constant, the needle will penetrate four times as far.

If, however, the second trolley has a different mass the needle may penetrate more or less than an inch.

100. (*a*) Unbalanced force is $80-30-20=30$ N.

(*b*) $F=ma$, $30=8\times a$, $a=\frac{30}{8}=3{\cdot}75$ m/s.

(*c*) $v^2=2\times\frac{30}{8}\times5$, K.E. $=\frac{1}{2}\times8\times2\times\frac{30}{8}\times5=150$ joules.

(*d*) P.E. $=$ gravitational force $\times$ distance $=30\times5=150$ joules $=$ potential energy gained.

(*e*) Friction force 20 N, $\therefore$ energy transformed $= 20 \times 5 = 100$ joules.

(*f*) Sum of $c+d+e = 400$ joules.

(*g*) This equals the work done by the applied force. 80 N acting through 5 m, requiring 400 joules.

101. (*a*) Time to fall 1·25 m under gravity $d = \frac{1}{2}gt^2$

$$1{\cdot}25 = \tfrac{1}{2}.10.t^2 = \frac{2{\cdot}5}{10} = \tfrac{1}{4},\ t = 0{\cdot}5 \text{ s.}$$

(*b*) velocity horizontally $= \frac{d}{t} = \frac{2}{\cdot 5} = 4$ m/s.

(*c*) Velocity just before it lands:

Downward component $v = at = 10 \times \frac{1}{2} = 5$ m/s

Horizontal component $v = 4$ m/s

$$\therefore \quad v = \sqrt{25+16} = \sqrt{41},\ \tan\theta = \frac{4}{5} = 0{\cdot}8.$$

(*d*) Momentum of ball leaving spring $= 0{\cdot}04 \times 4 = 0{\cdot}16$ kg m/s.

(*e*) Impulse on ball $= Ft = 0{\cdot}16$ Ns.

(*f*) $v^2 = 2ad,\ a = \frac{4^2}{2 \times 0{\cdot}02} = 400$ m/s^2.

(*g*) $Fd = \frac{1}{2}mv^2$ OR $F = ma$

$F \times 0{\cdot}02 = \frac{1}{2}.0{\cdot}04.4^2$ $\qquad = 0{\cdot}04 \times 400$

$F = 16$ N $\qquad = 16$ N.

(*h*) $v = at,\ 4 = 400.t,\ \therefore t = 0{\cdot}01$ s.

(*i*) K.E. $= \frac{1}{2}.0{\cdot}04.4^2$ OR K.E. $= Fd$

$= 0{\cdot}32$ joules. $\qquad = 16 \times {\cdot}02 = 0{\cdot}32$ joules.

(*j*) P.E. $= 10 \times {\cdot}04 \times 1{\cdot}25 = 0{\cdot}5$ joules.

(*k*) K.E. just before touching ground $= \frac{1}{2} \times 0{\cdot}04 \times 41 = 0{\cdot}82$ joules.

(*l*) P.E. just before touching ground $= 0$.

102. K.E. of hammer head $= \frac{1}{2}mv^2 = \frac{1}{2} \times 0{\cdot}6 \times 4^2 = 4{\cdot}8$ joules.

This equals $F \times d$ and $d = 0{\cdot}02$ m. $\therefore F = \frac{4{\cdot}8}{{\cdot}02} = 240$ N.

$Ft = mv$ or $F = ma$ where $v^2 = 2ad$ gives a.

103. (*a*) Momentum is conserved. Sandbag rises 0·08 m against gravity.

Then $v^2 = 2ad$ OR Gain in P.E. = Loss in K.E

$v^2 = 2 \times 10 \times {\cdot}08$ $\qquad mgh = \frac{1}{2}mv^2$.

$\therefore \quad v = \sqrt{1{\cdot}6}$.

This is velocity of sandbag and bullet after impact.

$\therefore \quad 0{\cdot}02.v = (7{\cdot}98 + 0{\cdot}02).\sqrt{1{\cdot}6}$

$\therefore$ velocity of bullet $= \frac{8\sqrt{1{\cdot}6}}{0{\cdot}02} = 400\sqrt{1{\cdot}6}$ m/s.

(*b*) K.E. before impact $= \frac{1}{2}.0{\cdot}02.(400^2.1{\cdot}6)$ joules

$= 2{,}560$ joules $= 2{\cdot}56 \times 10^3$ joules

K.E. after impact $= \frac{1}{2} \times 8 \times 1{\cdot}6 = 6{\cdot}4$ joules.

(*c*) The bullet used most of its energy in penetrating the sand. This energy is transformed into heat.

(*d*) Percentage mechanical energy remaining $= \dfrac{6{\cdot}4 \times 10^2}{2{\cdot}56 \times 10^3}\%$

$= 0{\cdot}25\%$.

104. Total mass accelerated $3 \times 10^4 \times 1{\cdot}7 \times 10^{-27}$ kg.
K.E. $= \frac{1}{2}.\ 3 \times 10^4 \times 1{\cdot}7 \times 10^{-27}(2 \times 10^7)^2$ joules
$= \frac{1}{2}.\ 3 \times 10^{-9} \times 1{\cdot}7 \times 4 = 1{\cdot}02 \times 10^{-8}$ joules.

105. $E = mc^2 = 0{\cdot}001 \times (3 \times 10^8)^2 = 9 \times 10^{13}$ joules.
1 kWh $= 3{,}600 \times 10^3$ joules $= 3{\cdot}6 \times 10^6$ J.

$\therefore$ Energy in 1 g $= \dfrac{9 \times 10^{13}}{3{\cdot}6 \times 10^6} = 2{\cdot}5 \times 10^7$ kWh.

Cost $= £\dfrac{2{\cdot}5 \times 10^7}{6 \times 20} = £2{\cdot}08 \times 10^5 = £208{,}000$.

106. (*a*) Acceleration $= \dfrac{v-u}{t} = \dfrac{22{\cdot}5 - 13{\cdot}5}{10} = 0{\cdot}9$ m/s^2.

(*b*) Mass 750 kg; $F = 750 \times 0{\cdot}9 = 675$ N.

(*c*) Frictional force $= 450$ N. $\therefore$ total force exerted $= 1{,}125$ N.

(*d*) Average speed during acceleration $= \dfrac{u+v}{2} = \dfrac{36}{2} = 18$ m/s.

(*e*) Power during acceleration is poorly estimated by force exerted $\times$ average velocity $= (1{,}125 \times 18)$ watts
$= 20{,}250$ watts.

(*f*) K.E.$_{13{\cdot}5} = \frac{1}{2}.\ 750 \times (13{\cdot}5)^2$, K.E.$_{22{\cdot}5} = \frac{1}{2}.\ 750 \times (22{\cdot}5)^2$
$= 6{\cdot}83 \times 10^4$ joules $\qquad = 1{\cdot}90 \times 10^5$ joules

107. (*a*) Acceleration $= \dfrac{20-10}{15} = 0{\cdot}66$ m/s^2 (assumed constant).

(*b*) $F = ma = 10^3 \times 0{\cdot}66 = 6{\cdot}6 \times 10^2$ N.

(*c*) K.E.$_{10} = \frac{1}{2}.10^3.10^2 = 5{\cdot}0 \times 10^4$ joules.

(*d*) K.E.$_{20} = 4 \times 5 \times 10^4 = 2{\cdot}0 \times 10^5$ joules or $= \frac{1}{2}.10^3 \times 400$ J. (Velocity doubled, energy quadrupled.)

(*e*) Work done $= 1{\cdot}5 \times 10^5$ joules.

(*f*) Power (estimate) $= \dfrac{15 \times 10^4}{15}$ watts $= 10^4$ watts.

(*g*) $Fd = \frac{1}{2}m(v_2{}^2 - v_1{}^2)$

$$d = \frac{15 \times 10^4}{6{\cdot}6. \times 10^2} = \frac{15 \times 3 \times 10^2}{20} = 2{\cdot}25 \times 10^2 \text{ m}.$$

(This again has a weakness at (*f*) for the power will be greatest when it is just finishing the acceleration. The force will be $\frac{2}{3} \times 10^3$ newtons and this force will move its point of application at the rate of 20 m/s.)

108. (*a*) K.E. $= \frac{1}{2}.10^3.10^2 = 5 \times 10^4$ joules.

(*b*) K.E. at rest $= 0$.

(*c*) Heat produced by brakes (assuming no wear of tyres or of road) $= 5 \times 10^4$ joules.
(*d*) Work done by retarding force $= F \times 20$ joules.
(*e*) Then $F = \dfrac{5 \times 10^4}{20} = 2{\cdot}5 \times 10^3$ N.
(*f*) $F = ma$, $a = \dfrac{v^2}{2d} = \dfrac{100}{2 \times 20} = 2{\cdot}5$ m/s^2. $\therefore$ $F = 2{\cdot}5 \times 10^3$ N.

109. (*a*) Max. P.E. $= 0{\cdot}1 \times 10 \times 1{\cdot}80 = 1{\cdot}8$ joules.
(*b*) This must be the K.E. it gets at the bottom.
(*c*) This must be the K.E. of the free ball before striking.
(*d*) $\therefore$ $\frac{1}{2}mv^2 = 1{\cdot}8$, $\therefore$ $v^2 = \dfrac{2 \times 1{\cdot}8}{0{\cdot}1}$, $\therefore$ $v = \sqrt{36} = 6$ m/s.

110. (*a*) Gravitational P.E. at A $= m \times g \times$ AC.
(*b*) Elastic P.E. at C $= m \times g \times$ AC since body is again at rest.
(*c*) K.E. at B = Total energy − gravitational energy at B − elastic energy at B $= m.g.\text{AC} - mg.\ \text{BC} - mg\text{AC}\dfrac{\text{AB}}{(\text{AC})}^2$.

(Energy of a spring $= \int F ds$ but $F \propto S$. So energy is proportional to square of the stretching.)

This ignores any change in the position of the spring itself or the K.E. gained by its own moving parts.

9 Heat and Hot (pp. 120–126)

Introduction

Pupils should revise the work of Chapter 10 in Book One before starting this new study of heat.

The mathematical treatment of the simple kinetic theory is not required at Ordinary Grade, for which a qualitative picture will suffice, but is necessary at Higher Grade and is therefore included for completeness (pp. 157–9). It could be used with a good fourth year class—without expecting them to be able to repeat the argument.

All the experiments in this chapter are essential but both alternatives in Experiments 9.1 and 9.3 need not be attempted. Experiment 9.1(*a*) is easier than 9.1(*b*)!

Questions 1 to 7 inclusive are suitable as home exercises. Questions (Problems) 8 to 12 are not essential but form a good basis for fruitful class discussion. The discussion arising from question 11 should lead the *class* to suggest Experiment 9.5.

Experimental Work

***Experiment* 9.1.** (*a*) The tube connecting the pressure gauge (N.67) to the flask should be as short as is practicable. It helps to support the gauge at a higher level than the flask.

(*b*) Fix the funnel to one end of the tubing and the glass tube and stopper to the other end. Use a 100 cm^3 flask and about two metres of tubing. Clamp the tubing, not the funnel, as shown in Fig. 211 and hold the other end, not yet attached to the flask, level with the funnel. Pour mercury into the funnel until it comes up to the stem of the funnel, then push the stopper into the inverted flask. Now use the screw clip to seal off the tubing as shown in Fig. 211. When measuring the head of mercury, i.e. the absolute pressure of the air in the flask, the position of the flask should be adjusted so that there is the minimum amount of air in the tubing between the flask and the mercury. In this way the volume of the air is kept constant.

It is possible to mark off a temperature scale on the metre stick. Zero pressure should indicate −273°C. Using the fixed points indicated in part (*a*) one should be able to obtain a value for absolute zero of between, say, −260 and −280°C in this way.

***Experiment* 9.2.** After switching off the heater (N.75) and stirring, wait a minute or two to allow the temperature to reach its maximum

value. Aerocups (Griffin and George Ltd, Braeview Place, East Kilbride, Lanarkshire) are available in 6 oz and 10 oz sizes. The latter are to be preferred here. 10 oz is approximately 280 cm^3, but these cups will hold 300 cm^3.

Experiment **9.3.** Using the 10 oz Aerocup instead of the polystyrene flowerpot one could use volumes of 150, 200 and 250 cm^3. Some polystyrene flowerpots allow water to seep through them. These should be avoided.

Experiment **9.4.** It is not intended that pupils should make calculations of the heat lost to the container when using copper calorimeters. The qualitative result is sufficient.

Experiment **9.5.** The instruction to stir with a glass rod and not with a thermometer can be ignored if the specially designed stirring thermometers are used. They are available from Philip Harris, W. B. Nicolson and Griffin and George Ltd.

ANSWERS TO QUESTIONS

1. The volume of air enclosed in the thermometer depends on the atmospheric pressure as well as on the temperature.

2. No.

Air pressure can still affect the air volume as it will be transmitted through the alcohol.

3. The scale range would not be very large. It could not be used below 0°C nor above 100°C. Because of the anomalous expansion of water 4°C would be further down the scale than 0°C.

Water also nearly always contains dissolved air. This air is apt to come out of solution in the thermometer as a little bubble—giving all the disadvantages of Galileo's thermoscope.

4. Sealing the top prevents evaporation or spilling of the alcohol.

5. Any gas inside the thermometer will increase in pressure as the temperature rises and this may burst the bulb. Removing all the gas means that the full range of scale to the top of the stem can be used. On the other hand many modern thermometers have an inert gas (often nitrogen) introduced into the top so that the increased pressure prevents the liquid from boiling or evaporating at temperatures near its normal boiling point.

6. 12 pennies = 1 shilling.
12 inches = 1 foot.
12 months = 1 year.

7. Probably the twelve prominent constellations of the Zodiac leading to a division of the year into twelve months.

8. Check which direction of pointer movement indicates a rise in temperature of the junction by holding the junction between finger and thumb. When the wet junction is removed from the liquid the pointer swings rapidly in the direction indicating cooling. The spirit is evaporating off the junction and the heat energy required is being drawn from the junction itself.

A reflecting galvanometer with a low terminal resistance (20 ohms or less) can be used instead of the galvo-amplifier illustrated in Fig. 212. The Pye Scalamp Model 7891/S and the Unigalvo Type 100 are suitable.

9. The blackened thermometer will show the greater rise in temperature, even when one takes care to make the circumstances equal —same type of thermometer, same distance from radiator, etc. The black surface is a better absorber of radiant energy.

10. This can happen if one of the two temperatures is between 0°C and 4°C, and the other is between 4°C and about 8°C. The volume of the water is a minimum at 4°C.

11. The best answer one can expect is 'We don't know; we will have to experiment to find out'.

Performing Experiment 9.5 will show that the copper has much less effect in cooling the hot water, than the same mass of cold water.

10 Thermodynamics (pp. 127–147)

Introduction

All pupils should read pages 127 to 132; we feel that the work of the pioneers in thermodynamics offers an admirable example of the ways in which theory and experiment affect one another and that this is valuable, though perhaps not examinable, knowledge.

The essential experiments here are those numbered 10.3, 10.4 and 10.7. Experiments 10.5(*a*) and (*b*) offer an easy introduction to electrical energy measurement and should certainly be included in Higher Grade work if not done before. Experiment 10.8 follows on this.

Questions 6 to 12, and 28 to 31, could be set to the better classes as homework; the remainder are suitable for all pupils.

Experimental Work

Fig. 216. 'Heath Robinson' was a comic artist who drew fantastic machines which could work.

Experiment (*Project*) **10.1.** This is a project—not an experiment that can be finished in an afternoon. It will take a number of weeks to get any sort of useful results but it is the kind of challenging problem that a keen pupil could tackle with benefit. Fig. 216 shows a short-circuited coil which is rotated in an insulating container. A current is made to flow in the coil by having the container between the poles of a powerful permanent magnet. The fall of the weights was timed by making the weight interrupt a beam of light falling on a photo-transistor of the kind used in Experiment 5.7(*b*) in Book Three. Such a project can lead to a useful discussion of errors.

Experiment **10.2.** This will work with a low-resistance reflecting galvanometer such as the Scalamp 7891/S or the Unigalvo Type 100. The Scalamp 7902/S, which has a higher terminal resistance, is not suitable. Lead foil folded so that there are about eight thicknesses on each side of the thermocouple will do instead of lead sheet. It is advisable to place the lead and the meter on separate supports, e.g. put the lead on a stool and the meter on a bench.

Experiment **10.3.** The Cottingham J Apparatus (see Fig. 220) consists of a solid metal cylinder having an axial hole bored to take a ther-

mometer; the cylinder is clamped between two felt pads. The cylinder is rotated against the friction due to these pads by pulling on the string, as shown in the diagram. A force of 10 newtons acting through a distance of 6 metres will give a suitable rise in temperature. The force is measured directly on a spring balance calibrated in newtons (N.81). Some of the models of this apparatus have a cylinder which is too long to fit into the 6 oz Aerocup and a larger container (such as a flowerpot) has to be used.

Experiment **10.4.** The most direct way of obtaining a force of 100 newtons is to hang weights on a balance calibrated in newtons and adjusting until the balance reads 100 N. If no such balance is to hand then hang a mass of 10·2 kg on the end of the cord. Since the gravitational field of the Earth is approximately 9·8 N/kg the weight of the 10·2 kg mass is 100 N. The heat from the copper drum reaches the thermometer mainly by radiation and it is therefore necessary to wait a few minutes before reading the temperature to allow the thermometer to attain its maximum temperature.

To compensate for the heat lost to the air during the experiment allow the temperature to fall to about the middle of the range. Take off the load, keep everything else as before and do 100 turns as before. Note the fall in temperature and *add* this temperature change to the original rise in temperature. This simple modification, readily accepted by the class, brings the answer much nearer to the accepted value.

Experiment **10.5.** The electric heater built into this drum is rated at about 10 watts. This is to make the rates of heating, mechanical in Experiment 10.4 and electrical here, approximately the same. One could also try to insulate the cylinder in the same way as in Experiment 10.4 by wrapping the nylon cord around it. This makes the conditions in the two experiments more nearly alike.

A kilowatt hour meter carries a plate on which is stated the number of revolutions of the disc which correspond to 1 kWh and the number of joules per revolution can be readily calculated from this.

Experiment **10.6.** A low-resistance reflecting galvanometer can be used in place of the Galvo-amplifier. (See the note on Experiment 10.2.)

Experiment **10.7.** Any method is bound to lead to a very crude estimate of the rate of heat supply. It is suggested that the spirit or gas burner be placed below a container of approximately the same length and width as the boiler of the model steam engine (N.9). The container should hold a known mass of water. The fuel is ignited and the

rise in the temperature that occurs in, say, two minutes is noted. The rate at which heat is delivered to the water is calculated (in joule/min) and it is then assumed that heat is given to the water in the boiler at the same rate. The value found for the efficiency is very, very low.

The Malvern Energy Conversion Kit (N.9) enables one to do the whole of the experiment.

***Experiment* 10.8.** As a demonstration experiment this is best done with a fractional horsepower motor (e.g. N.150). However, it would be more satisfactory to do this as a class experiment using the motor from the Malvern Kit (N.9) or the Small Electric Motors Kit (N.155) together with suitable meters.

***Experiment* 10.9.** (*a*) The tin and its lid should be clean, free from rust and undistorted. The lid of a 2-oz 'instant' coffee tin should rise 12 or 15 ft above the tin.

(*b*) One of the elastic cords used in the trolley experiments is suitable here. Tie a 5 g weight to it and heat it with a roaring Bunsen flame from a distance of about 3 in.

***Experiment* 10.10.** The bands which are heated contract and bring the rim on that side nearer to the hub. Hence the weight of the rim on the heated side will have a smaller turning moment than that on the cool side. This will cause the wheel to turn anticlockwise (as shown in Fig. 243). When a spoke moves away from the source of heat it will cool and regain its original length. Thus the process is a continuous one.

Yes, this is a heat engine just as the one shown in Fig. 242.

ANSWERS TO QUESTIONS

1. One answer might be to try putting a lump of solid carbon dioxide at the focus of one concave mirror and a thermometer bulb at the focus of another. Line the two mirrors up and see whether the temperature shown by the thermometer drops.

2. Unless the waterproofing is very good the churning might result in wetting parts of the container which are open to the atmosphere. The consequent evaporation of this water could produce cooling. Another possibility is that the water and container were not at the same temperature at the start of the experiment.

3. The temperature should be higher at the bottom.

4. The potential energy that the water loses in falling is converted first into kinetic energy and then into heat energy when it hits the bottom.

5. Heat needed to raise temperature of 1 kg of substance by 1°C is s J.

Heat needed to raise temperature of m kg of substance by 1°C is sm J.

Heat needed to raise temperature of m kg of substance by ΔT°C is $sm\,\Delta T$ J.

6. There is confusion between 'perpetual motion' and 'perpetual movement'.

Nuffield Physics Teachers' Guide 1 (Harmondsworth: Longmans/Penguin Books, 1966, pp. 34, 35).

The latter is indeed possible—our Moon, gas molecules, etc. A 'perpetual motion' machine, in the traditionally accepted sense, is not just something that keeps on running. It is a machine that puts out more energy than it takes in. The output therefore must be more than sufficient to provide the necessary input. This contradicts the principle of conservation of energy.

7. The weights on the right-hand side are further from the axle of the wheel and therefore have a greater turning moment than those on the left-hand side, so tending to turn the wheel clockwise.

8. Although the left-hand masses are nearer the axle, there are more of them; so that the total anticlockwise moment is equal to the clockwise one, and the wheel does not turn. Furthermore, if one did start the wheel turning, the potential energy lost by each mass as it fell on the right-hand side must be equal to its gain of potential energy as it rises on the left-hand side. If there were no friction at the axle, and so no energy changed into heat, such a device would provide perpetual *movement*.

9. Expanding air from the heated flask displaces water from the second flask into the can; the can becomes heavier and falls, pulling up the counterweight and moving the pointer to 'open'. When the burner is removed the air contracts and atmospheric pressure pushes water back from the can into the flask; the can becomes lighter and is pulled up by the counterweight.

10. As the steam condenses the pressure in the flask is reduced. The atmospheric pressure acting on the surface of the water in the mine forces water up the pipe, through valve B, and into the flask.

11. Close valve B, but open A and C.

Steam from the boiler will then force water out of the flask and up to the surface.

12. When the piston has reached each end of its stroke, i.e. when the piston and its connecting rod are in a straight line.

13. Inlet valve closes, outlet (exhaust) valve opens and the rising piston pushes the burnt gases out—through the exhaust pipe.

14. (*a*) None. (*b*) Outlet.

15. Third.

16. The kinetic energy stored in the massive flywheel which is made to rotate during the power stroke.

17. More efficient than a steam engine. But note that steam-generating stations can be up to 35% efficient.

18. The heat is produced outside the cylinder of the steam engine and a lot is wasted in the exhaust gases (up the chimney) and to the air around the boiler.

19. To protect the occupants from the heat generated during re-entry into the atmosphere.

The space-craft does not travel fast enough during blast-off for the air friction to be serious.

20. Sound from a loudspeaker can be received by a microphone and used to move pointers on electric meters, showing the energy changes sound—electricity—kinetic and potential energy. It is also possible to light small electric lamps direct from the microphone (Microlamps from H. F. Collison (Goodwell) Ltd, Coleshill, Birmingham). This shows the change sound—electricity—light. Sunlight, or the light from a 150-watt lamp, can be used to energise solar batteries to drive a small motor (Hoffman Solar Energy set from Griffin and George Ltd) or solar batteries (Proops Bros Ltd, 52, Tottenham Court Road, London, W.1) can power a small transistor radio.

There are further examples in Chapters 5 and 8 of Book Two.

21. (*a*) The strain set up in rocks by expansion and/or contraction may be large enough to split them, or to break off small particles.

(*b*) Winds are the result of convection set up by uneven heating of the atmosphere by contact with the Earth.

(*c*) Volcanoes are formed at places where the Earth's crust is thinner. A fracture allows molten rock and steam from the very hot interior of the Earth to be thrown out.

In the first two cases the heat energy comes from the Sun. The interior of the Earth is heated by radioactive elements in the core.

22. Yes.

23. No.

The electrical energy supplied to the fan motor is converted into kinetic energy of the air and this will eventually change into heat energy, when the air slows down. Some heat will also be produced by friction at the fan bearings.

24. There is no such thing as 'the cold' (except in the medical sense!). The open door may let in cold air but only at the expense of warmer air being displaced out of the room, e.g. up the chimney.

25. Because one piston must be driven through the first and second strokes (see p. 141, Book Three) before the power (third) stroke occurs and to do this kinetic energy must be supplied to the moving parts such as the piston, connecting rod and flywheel.

26. Most electrical energy is produced from chemical energy (in coal or oil) by means of steam engines (turbines). This conversion is about 30% efficient so that the *overall efficiency* of an electric locomotive is roughly 25%. The reason that all trains are not powered by electricity has more to do with economics than physics—capital tied up in existing locomotives and antiquated track, the cost of the overhead power lines and so on.

27. Heat—mechanical.

28. *c*; *b*; *d*; *a*; *e*.

29. The more mixed up the balls appear, the more shaking has taken place.

30. There would be no orderly appearance in the arrangement of the balls and they would look much the same as in Fig. 245(*e*).

31. A very long time!

There is always the possibility that it will happen, but with this number of balls the probability is vanishingly small.

11 Freedom and State (pp. 148–155)

Introduction

In this chapter we are dealing with the quantities of energy required to raise the temperature of a substance and also to change its state. It is therefore essential that the following experiments be done:

Experiment 11.1 (*a*) or (*b*) or (*c*).
Experiment 11.2 (*a*) or (*b*).
Experiment 11.4 (*a*) and (*b*) and (*c*).
Experiment 11.6.
Experiment 11.7 (*a*) or (*b*).
Experiment 11.9.
Experiment 11.10 (*a*) or (*b*).

This is the bare minimum. Next in order of importance are Experiments 11.11, 11.12, 11.13 and 11.14.

Questions 5, 9 and 27 require the knowledge that K.E. $= \frac{1}{2}mv^2$. The remainder of the questions, up to No. 46, are suitable for home exercises for all classes. Nos. 47 to 51 should be set only to those pupils who have studied the 'Optional Extras'.

Experimental Work

***Experiment* 11.1.** The immersion heaters (N.75) are rated at approximately 50 watts. We make the assumption that all the heat developed by the heater is delivered to the liquid. Since the range of temperature is less than 20°C (with the Aerocup full of liquid) for a heat input of 1,000 J, and the Aerocup is a good insulator, this assumption is a reasonable one to make in the interests of simplicity of calculation.

It is always advisable to check that the liquids to be used do not dissolve the plastic container. For example, turpentine will dissolve the Aerocups supplied by Dobbies Paper Supplies.

***Experiment* 11.2.** Aluminium blocks (N.77) and blocks of other metals (iron and brass) are available from the main suppliers (numbered 3, 4, 9 and 20 on p. 165 of Book Three). The drop of oil is not really necessary but it does help to make good thermal contact between the block and the thermometer and so speed up the transfer of heat to the thermometer. Mercury should not be used as it attacks most metals and its vapour is toxic.

***Experiment* 11.3.** The result is a gross underestimate because of the heat lost to the surrounding air.

***Experiment* 11.4.** (*a*) Your hand feels cold because the heat energy removed by the evaporating ether has been provided by your hand.

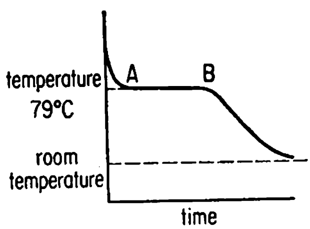
(*b*) In a closed bottle a condition of dynamic equilibrium will soon be set up in which there is no net loss of molecules from the liquid. Energy taken from the liquid by escaping molecules is returned as molecules pass back from the vapour to the liquid and the liquid will be at room temperature.

In the open dish the energetic molecules which escape from the surface of the liquid are likely to be swept away by air currents and so have much less chance of returning to the liquid, i.e. the total energy of the liquid is lowered—it is cooled.

***Experiment* 11.5.** See the answer to Practical Puzzle No. 8 (p. 123 of Book Three) on page 52.

***Experiment* 11.6.** The water freezes. The air current prevents the molecules returning to the liquid and so the most energetic molecules are rapidly removed. This means that the ether is cooled, heat flows into it from its immediate surroundings and the water is thus cooled below 0°C. Temperatures down to about -15°C can be attained in this way. A double-acting foot bellows or the outlet of a vacuum cleaner will provide an adequate air flow.

***Experiment* 11.7.** The naphthalene cools down very quickly and readings must be started immediately the flame is removed.



At A the naphthalene begins to solidify and (latent) heat is evolved as the molecules give up their extra energy. The rate at which liquid naphthalene can solidify depends on the rate at which it can lose its latent heat. This will equal the rate at which heat can be lost to the atmosphere. Hence the temperature remains constant until practically all the liquid has frozen (at B)—from then on cooling will occur in the usual way.

***Experiment* 11.8.** The ice formed will more than fill the thimble whereas the paraffin will have shrunk.

The diagrams (Figs. 251 and 252 on p. 151 of Book Three) give some idea of the arrangement of the H_2O molecules—they take up *more* room in the solid state. In paraffin the molecules are more closely packed in the solid, which therefore takes up less space than the same mass of liquid.

***Experiment* 11.9.** It is essential that the pieces of ice are small and that they are kept in intimate contact with the heater. In this way it can be assumed that all the heat produced by the heater goes to melt the ice.

The second set is a 'control' experiment. This enables one to find the mass of ice that would have melted in the same time without switching on the heater. This mass should be subtracted from that collected in the other beaker to find the mass actually melted by the heater.

***Experiment* 11.10.** (*a*) A flowerpot with nearly vertical sides is best. Any heater rated up to 500 watts can be used; anything higher will cause the water to boil too vigorously and splash over. Make sure that the water is boiling really briskly before doing any measurements.

(*b*) When calibrating the heater it is advisable to have it switched on for one minute only, otherwise the rise in temperature is too great and heat losses to the air will invalidate the measurements.

***Experiment* 11.11.** When salt goes into solution heat is absorbed from the water and the temperature falls.

The freezing point of the solution is lower than that of pure water. A saturated salt solution freezes about $-22°C$.

***Experiment* 11.12.** One method is the classic one of hanging a weight (about 3 kg) from a piece of wire looped over a block of ice. The wire should be a good conductor. The ice below the wire melts under the extreme pressure; the heat required is taken from the water above the wire by conduction through the wire. This causes the water above the wire to freeze once again and the wire will slowly pass through the block leaving it unbroken. The process will take about an hour for a block 3 in wide and $\frac{1}{2}$ in thick.

***Experiment* 11.14.** A tapered stopper must be used here. If a cylindrical one is used it will be forced up the neck of the flask by atmospheric pressure and the thermometer will be shot through the top of the flask—showering the class with hot water and broken glass.

The pressure inside drops as the water vapour condenses. A liquid boils when its vapour pressure is equal to that on its surface. Since the pressure in the flask has been lowered the water will boil at a reduced temperature.

A round-bottomed flask is used here as it can withstand the pressure difference better than one of any other shape.

ANSWERS TO QUESTIONS

1. 30°C.
2. 315.
3. 97°C.
The energy generated is used to drive all the automatic functions of the body—such as the beating of the heart, breathing and digestion. The body also loses energy, as heat, by convection, radiation, the breathing out of water vapour and by the evaporation of sweat, and by other warm excretions.
4. 26·5 m (taking g as 9·8 m/s^2).
26 m (taking g as 10 m/s^2).
5. 19·3°C.
6. (*a*) 126,000 J, (*b*) 126,000 J, (*c*) 1310°C.
7. 0·58°C.
8. 630 N (to two significant figures).
The main loss is as heat energy from his body to the water.
9. 2×10^6 J.
10. $1{\cdot}7 \times 10^6$ J; 1,600 kcal.
11. Electricity is 2·4 times as expensive as gas.
10^6 J of electrical energy cost 2/3·6 pence = 0·55d.
10^6 J of energy from gas cost 24/105·5 pence = 0·23d.
At off-peak rates electricity costs $\frac{2}{5}$ of the full rate, i.e. 0·22d per 10^6 J, while cheap-rate gas costs $\frac{3}{4}$ of the full rate, i.e. 0·17d per 10^6 J.
12. If we assume that the water level in the reservoir is 300 m above the turbine each kilogramme of water will carry a maximum of $300 \times 9{\cdot}8 = 2{,}940$ J of energy into the power station. Even if all this were converted to heat in the water the rise in temperature would be only $2{,}940/4{,}200 = \frac{3}{4}$°C approx.
OR
Taking $g = 10$ N/kg the P.E. lost by the water $= mgh$ J. Assuming that the water is at 20°C the heat needed to raise its temperature to boiling point $= sm\Delta T = 4{,}200 \times m \times 80 \times$ J.
So we have: $m \times 10 \times h = 4{,}200 \times m \times 80$
Whence $h = 33{,}600$ m. Hardly likely!
13. Yes.
Because the same mass now occupies more space and so the density has decreased (see Experiment Project 11.8).
14. No.
Because the same mass occupies less space and so the density has increased (see Experiment Project 11.8).
15. The water in the lake loses heat from its surface. As the surface

water cools it sinks and warmer water rises from the bottom to be cooled in turn. But at 4°C, the temperature of maximum density of water, this process ceases. At lower temperatures the coldest water will be at the surface and the only way in which the lower, warmer water can cool further is by conduction of heat through the surface layers—and water is a very bad conductor.

16. The weight of the ice equals the weight of water it is displacing—so when the ice melts the water formed just fills the 'submerged space' and the level remains the same.

17. If both houses had been originally covered with snow and both were heated equally then the snow-covered house would be warmer because it had better insulation. On the other hand the snow-covered house could be empty, not heated, in which case the other would be warmer.

18. Black. The black surface absorbs the radiation from the Sun better than the white, which reflects a lot of it.

19. Placing ice in it.

When the can is set on the ice the melted ice runs off without being heated any more and the cooled water stays at the bottom of the can. When the ice melts in the can it absorbs more heat as the hot water warms it. The ice in the can will be in contact with a greater surface area of water and so the heat transfer will be more rapid, and the cooled water sinks and allows the warm water to take its place.

20. The ice will melt and the blocks will sink into it to different depths which will depend on how much heat the blocks can give out before cooling to 0°C. Since the blocks have the same mass the depths will be proportional to the specific heats. The result will be modified to some extent by heat being lost off the upper surfaces of the blocks by radiation and convection, which will be different for each block.

21. Yes. The molecules in a kilogramme of water at 0°C have more energy than the molecules in a kilogramme of ice at 0°C. Energy (heat) had to be supplied to the ice, to overcome the forces of attraction between the molecules, to enable it to melt. When the water freezes this energy has to be given out—as heat.

22. Because the water must lose latent heat to the surrounding atmosphere before it freezes, and this heat energy cannot be got rid of instantaneously. Also the processes of conduction and convection are fairly slow—see the answer to question 15 above.

23. Because it changes directly from solid to gas without going through the liquid state.

24. $16{\cdot}7 \times 10^3$ J.

25. 0°C; the ice will not all melt.

26. 16 g.

27. 37 g.

28. 15·6 g; 0°C.

29. Yes. The steam has lost latent heat in changing to water, even though its temperature has not changed.

30. Draughts will increase the rate of evaporation of moisture from the skin and so draw great quantities of latent heat from the body. This might produce a chill.

31. No. Latent heat must pass through the tin in order to boil the water in it. This cannot happen unless the temperature outside the tin is higher than the temperature inside. Thus the water outside the tin would have to be at a greater temperature than 100°C before it would boil water (boiling point 100°C) inside the tin.

32. Human beings have a 'built-in' control mechanism which maintains their bodies at a more or less constant temperature. Part of this mechanism consists of the evaporation of perspiration from the skin. This removes latent heat from the body. If the atmosphere is very humid it contains a large amount of water vapour and it becomes more difficult to evaporate any more into the atmosphere. We thus experience discomfort in a humid atmosphere because our rate of evaporation of perspiration has been slowed down. High temperatures in a dry atmosphere merely lead to a more rapid evaporation of perspiration, so that we feel less discomfort than in a humid atmosphere.

A better explanation would be in terms of dynamic equilibrium between the molecules escaping from the liquid state and those returning to it. The evaporation rate depends only on the temperature —not on the humidity. A high humidity means a high rate of return of molecules from the gaseous to the liquid state, and hence little net evaporation.

33. In a hot dry climate—for the reasons given above. The sweat will evaporate rapidly and keep you cool.

34. A dog's body temperature is controlled not by sweating but by breathing out water vapour and by evaporating moisture off its tongue. Panting increases the rate of both these processes.

35. The part of the atmosphere (the troposphere) which is responsible for our weather is largely heated and cooled by contact with the Earth. It will therefore be at its coldest shortly after the ground is at its coldest, i.e. just before sunrise. There is then the greatest likelihood that some of the water vapour will be sufficiently cooled to give out its latent heat and form water droplets, i.e. fog. Similarly, as the Earth warms up during the day—an effect which is delayed by the 'blanket' effect of the fog itself which tends to reflect the Sun's rays and prevent them reaching the Earth—the air will warm and the fog will change back into invisible water vapour.

36. No.

The water will boil off at a faster rate but the temperature will not rise and it is this which determines the cooking rate.

37. The liquid seeps through the pores of the pot to the outside surface from which it evaporates. This removes latent heat from the contents, thus keeping them cool.

38. 40 g.

39. 295 g.

Assuming that only the water which is evaporated is heated up to 100°C we have:

$$2 \times 800 \times 440 = m \times 30 \times 4{,}200 + m \times 2{\cdot}26 \times 10^6$$

where m is the required mass.

40. 43 kg.

41. 33·4 g.

42. 'Anti-freeze' dissolved in the radiator water lowers the freezing point so that the water will not freeze even if its temperature drops below 0°C. Water expands on freezing and this expansion could burst the radiator or crack the cylinder block. Furthermore, if ice forms in the radiator it interrupts the flow of cooling water to the engine, the engine becomes overheated and the water at the top of the radiator boils—not a rare sight in very cold weather.

43. Tea infuses properly only if the water is at or near 100°C. This is impossible if the atmospheric pressure is reduced, as it is on a high mountain, since the water boils at a lower temperature. For example, on the top of Mont Blanc water boils at about 85°C. The solution is to use a pressure cooker.

44. It is easier when the temperature is just below freezing.

Pressure on the ice makes it melt (since ice occupies more volume than the same mass of water) so that the skater travels on a layer of water, which is nearly frictionless. The colder the ice the more pressure is needed to melt it.

45. Because of the different way in which they are arranged water molecules are closer together than ice molecules (see Figs. 251 and 252 of Book Three). Pressure on the ice tends to break up the ordered arrangement of the molecules by forcing them closer together, i.e. changing the ice to water. Thus increasing pressure tends to convert ice to water, so lowering the melting point.

46. Greater.

The steam is kept inside the cooker and so the pressure builds up. A safety valve prevents the pressure becoming dangerously large.

47. To produce convection currents in the refrigerator. Cooling the air at the top makes it more dense so that it sinks down, displacing warmer air from the bottom to the top. This warmer air is then cooled in its turn.

48. No.

49. The heat taken in through the open door of the fridge is given out again at the rear when the Freon condenses.

50. We do get more heat energy out than the electrical energy put in—but the heat energy does not come only from the electrical energy. The heat energy given out is obtained by cooling down the contents of the refrigerator. The electrical energy is used to drive the pump which moves the 'heat-carrying substance', i.e. the Freon.

51. 4 g; 62·5 minutes.

12 Model Making (pp. 156–164)

Introduction

Sufficient experimental work must be done to establish the validity of the simple kinetic theory. This means that Experiments 12.2, 12.5 (or 12.4) and 12.6 (*a*) or (*b*) should be performed. The remaining experiments should also be attempted, if time permits, as they will help to fill in detail and to strengthen the pupil's understanding.

Questions (Problems) 6 and 12 could be used in class with those who have tackled the mathematics on pages 158 and 159. All the others are useful home exercises.

Experimental Work

Experiment **12.1.** Use commercially available dry ice pucks (part of N.95).

The magnets exert a force on the strip equal and opposite to the force that the strip exerts on the magnets.

There is still some friction (air resistance), and the collisions are not absolutely perfectly elastic.

Experiment **12.2.** The kinetic model kit (N.11) which is driven by an electric motor (N.11/100 or N.150) provides more energetic 'molecules' than one driven by an Advance vibrator or a loudspeaker, and makes it easier to demonstrate the gas-like behaviour of the nickel spheres.

Experiment **12.3.** The reading is much smaller when the plasticine ball, which does not rebound, is used—both the rate of change and the change in momentum is smaller.

Experiment **12.4.** The tubing should be about two metres long. Attach the syringe and the filter funnel to the tubing and support the funnel end, as shown, by gripping the *tubing* in the retort stand clamp. Set the syringe for a volume of about 50 cm^3. As the mercury is poured in raise the syringe so that the volume remains at about 50 cm^3 (it is easier with two people). Continue to do this until the longer limb is full and then clamp it. This must be air-tight.

When the readings are being taken the piston must be forcibly held at the required position and one must be sure that there is a space (vacuum) at the top of the longer limb.

The volume of any air in the syringe end of the tubing will not be measured and so must be reduced to a minimum.

The product pV should be constant to within 1 or 2% and this supports the simple kinetic theory.

***Experiments* 12.5 *and* 12.6** are fully explained in the text.

***Project* 12.7.** All the gas molecules are moving at the same (average) velocity and so the number hitting any square centimetre of piston or cylinder wall per second is the same throughout. But the total force on a piston will be determined by its area in square centimetres. Hence the forces (total weights) on each side will be found to be proportional to the area of the pistons.

***Project* 12.8.** The results obtained will be very variable. Sometimes the tumbler will slide down the sloping glass, or Formica draining board, as if it were supported on a cushion of air. Probably air expanded by contact with the warm tumbler. At other times one will see soap bubbles blowing into the tumbler as the warm air inside it cools down. This occasionally lowers the pressure in the tumbler sufficiently to make it stick to the smooth surface. Every case poses a problem for explanation in terms of the behaviour of a heated, or cooled, gas.

ANSWERS TO QUESTIONS

1. Because the movement of the visible smoke particles is continuous and random. If matter were continuous there would be no such motion and if it were due to any outside effect, e.g. vibration of the cell, it would sooner or later run down and stop.

See *Nuffield Physics Teachers' Guide* 1 (Harmondsworth; Longmans Penguin Books, 1966. pp. 232–7).

2. (*a*) The pressure will increase.
More gas molecules will hit the walls of the container each second.

(*b*) Again the pressure will increase.
The molecules move faster than before, they hit the walls of the container with greater momentum.

3. Experiments 9.1 and 10.6 in Book Three.
Experiments 10.17 and 10.19 of Book One.

4. They will exert more force.

5. The force each molecule exerts is proportional to the change in its momentum during the collision. Let its mass be m and its velocity before hitting the piston (or container wall) be v. Then we have:

	Momentum before	*Momentum after*	*Change in momentum*
Elastic collision	mv	$-mv$	$2mv$
Inelastic collision	mv	$-\frac{1}{2}mv$ (say)	$1\frac{1}{2}.mv$
Completely inelastic collision	mv	0	mv

6. (*a*) 5 kg m/s, (*b*) −5 kg m/s, (*c*) −10 kg m/s, (*d*) +5 kg m/s, (*e*) −200 kg m/s,

On the steel wall $\frac{\Delta mv}{\Delta t} = \frac{200}{1}$

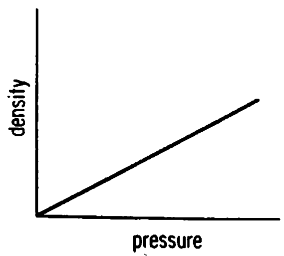
$= 200$ newtons.

(*f*) 50 N/m^2, (*g*) 25 N/m^2.

7. Yes.

If the volume of the gas is reduced, at the same temperature, the number of collisions of the molecules of the gas with the walls of the container in each second will increase, i.e. the pressure will increase.

8.



9. (*a*) 2×10^5 N/m^2; (*b*) 5×10^5 N/m^2.

10. 375 cm^3.

11. The pressure at the top of the stroke will be eight times as great.

12. Yes.

13. Pushing in the piston, with the outlet closed, does two things. Molecules rebounding from the piston will move faster than before (the gas temperature rises) and the molecules will have less space in which to move about. Thus the number of collisions per second on the pump side of the pellet will be greater than on the other side. There will be an unbalanced force on the pellet and it will accelerate outwards.

14. Raising the temperature raises the average kinetic energy of the molecules by increasing their speed. They will therefore collide with the container walls more often, so that the number per second hitting

1 cm^2 of wall will increase. Each molecule making an elastic collision with the wall changes its momentum by $2mv$. Thus, both because there are more collisions per second and because they collide with greater momentum, will the molecules exert a greater pressure as the temperature rises.

15. 1 mile per second.

The average K.E., and therefore the speed, depends only on the temperature, which has not changed.

16. The hydrogen molecules.

At the same temperature they both have the same average K.E. per molecule, i.e. $\frac{1}{2}mv^2$ is the same for both. Since hydrogen has the smaller mass m, its molecules must have greater velocity v to give them the same K.E. as the oxygen molecules.

17. Greater.

The tyre is being continually deformed in its contact with the road. This means that as the wheel revolves the rubber molecules rub and grind against one another. This friction generates heat and some of the heat will be given to the air molecules in the tyre. The volume stays almost constant and so the pressure will rise.

18. Less.

When a molecule is near the 'edge' of a gas, i.e. about to collide with a wall, the resultant direction of the attraction of the rest of the gas molecules on it will be inwards—simply because there are more gas molecules on that side. This pulls the molecule back; slows it down so that it hits the wall with less speed than if there had been no attraction.

19. (*a*) Solid molecules are held together by strong attractive forces between the molecules (atoms). At any temperature above absolute zero the molecules are vibrating but cannot free themselves from the attractions of their neighbours. The molecules are thus kept in position and the solid keeps its shape.

In a liquid the molecules have greater K.E. The faster vibrations have *partly* broken down the forces which held each molecule in place so that they are now free to move about, colliding with each other, but they are still about as close together as in the solid state.

In a gas the molecules have so much K.E. that the bonds between them are almost completely broken and they move much more freely. They collide elastically with other molecules and do so with such vigour that they are kept much further apart. The attractions between them are now much too weak to make them 'stick' together when they collide.

(*b*) Pressure is force on unit area and force is the rate of change of momentum. When a gas molecule collides elastically with a container wall it rebounds with the same speed in

the opposite direction, so that the change in momentum is $mv-(-mv)=2mv$. If there are n molecules hitting 1 cm^2 of wall every second the pressure will be $2nmv$ since this is the rate of change of momentum on unit area.

(*c*) Raising the temperature raises the average K.E. and so the average speed of the molecules. If they are to collide with the container walls with the same effect as before (exerting the same pressure as before) the walls will have to be farther apart. Thus the gas must expand as the temperature rises—assuming it is to be kept at the same pressure.

(*d*) There is no change in temperature when a substance changes state, so the average K.E. of the molecules is the same. But work has to be done against the intermolecular forces which bind the molecules together as a solid or liquid, i.e. the molecule has to be pulled away against the attraction of its neighbours. The energy needed for this is the latent heat.

20. The Gas Board.

For the same volume (same cost) the lower the pressure the less the density of the gas. This means fewer molecules and therefore less heat—since each molecule gives up the same quantity of energy in burning.

21. (*a*) No change.

(*b*) The speed is increased on rebound.

(*c*) The speed is reduced on rebound.

Compressing a gas is the same as (*b*). The molecules meet a container wall (perhaps a piston) closing in on them. This increases the average speed of these molecules so raising the K.E., i.e. raising the temperature.

22. 5·8 m^3.

23. 1·6 m^3, 1·3 kg/m^3 at sea-level, 0·63 kg/m^3 at 5·5 km.

24. The rate increases with altitude since he must inhale a larger volume in a given time in order to get the same mass of oxygen into his lungs.

25. 0·6 cm^3.

26. 45·8 cm^3.

27. Three times as dense.

28. 3×10^5 N/m^2.

29. The same number of molecules occupy 750 times as much space in the gaseous state as in the liquid state. This means that their spacing is about $\sqrt[3]{750}$ times as great in the gas, i.e. between 9 and 10 times. (Think of eight balls arranged in a cube. If the spacing between them is doubled the volume is increased by a factor of 8, i.e. 2^3.)